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RESEARCH ARTICLE

Integrating technology into K-12 teaching and learning: current knowledge gaps and recommendations for future research

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Abstract Although research studies in education show that use of technology can help student learning, its use is generally affected by certain barriers. In this paper, we first identify the general barriers typically faced by K-12 schools, both in the United States as well as other countries, when integrating technology into the curriculum for instructional purposes, namely: (a) resources, (b) institution, (c) subject culture, (d) attitudes and beliefs, (e) knowledge and skills, and (f) assessment. We then describe the strategies to overcome such barriers: (a) having a shared vision and technology integration plan, (b) overcoming the scarcity of resources, (c) changing attitudes and beliefs, (d) conducting professional development, and (e) reconsidering assessments. Finally, we identify several current knowledge gaps pertaining to the barriers and strategies of technology integration, and offer pertinent recommendations for future research.

Keywords Technology integration · Barriers · Strategies · K-12 · Curriculum · Future research

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Introduction

From the birth of the motion picture in 1922, to the advent of the computer in the mid-1970s, educators have been intrigued with the potential of technology to help transform education and improve student learning. Research studies in education demonstrate that the use of technology (e.g., computers) can help improve students' scores on standardized tests (Bain & Ross, 1999), improve students' inventive thinking (e.g., problem solving) (Chief Executive Officer (CEO) Forum on Education and Technology, 2001), and improve students' self-concept and motivation (Sivin-Kachala & Bialo, 2000). Moreover, technology is also seen as being able to provide a number of opportunities that would otherwise be difficult to attain. The use of computer-mediated communication tools, for example, can help students from various geographical locations "talk" to one another and experts conveniently. The increased ability to communicate with experts enhances students' learning process (Bransford, Brown, & Cocking, 2000).

The belief that technology can positively impact student learning has led many governments to create programs for the integration of technology in their schools. In the United States, school districts reportedly spent $7.87 billion on technology equipment during the 2003–2004 school year (Quality Education Data, 2004). The student-per-instructional computer ratio dropped to 3.8:1 in 2004, whereas the student-per-Internet-connected computer ratio dropped to 4.1:1 (Education Week, 2005).

In Singapore, the first Master plan for Information Technology in Education was launched in April 1997. This program cost approximately $1.2 billion. As part of this plan, all Singapore schools are expected to acquire and integrate technology in their curriculum in order to develop in students a culture of thinking, lifelong learning, and social responsibility. More recently, the Singapore government unveiled the second Master plan for Information Technology in July 2002 to continue to provide overall direction on how schools can harness the possibilities offered by information technology for teaching and learning.

Although research studies in education show that use of technology can help student learning, its use is generally affected by certain barriers. These barriers are all too prevalent—even among exemplary users of technology in schools (Becker, 2000). The purpose of this paper is to examine the current barriers related to the integration of technology into the curriculum that are currently faced by K-12 schools both in the United States and in other countries, and to identify strategies to overcome those barriers. In addition, we identify current knowledge gaps in the literature and provide recommendations for future research.

What is technology integration?

There is no clear standard definition of technology integration in K-12 schools (Bebell, Russell, & O'Dwyer, 2004). For some scholars, technology integration was understood and examined in terms of types of teachers' computer use in the classrooms: low-level (e.g., students doing Internet searches) or high-level use (e.g., students doing multimedia presentations, collecting and interpreting data for projects) (Cuban, Kirkpatrick, & Peck, 2001). For other scholars, technology integration was understood and examined in terms of how teachers used technology to carry out *familiar* activities more reliably and productively, and how such use may be re-shaping these activities (Hennessy, Ruthven, & Brindley, 2005). Still others consider technology integration in terms of teachers using technology to develop students' thinking skills (Lim et al., 2003). Despite the lack of a clear standard definition, certain prevailing elements appear to cut across the many different current discussions about technology integration in K-12 schools. These elements typically include the use of computing devices for instruction. In this paper, technology integration is thus viewed as the use of computing devices such as desktop computers, laptops, handheld computers, software, or Internet in K-12 schools for instructional purposes.

Analysis of previous research studies

To examine the current barriers and strategies, we analyzed existing studies from 1995 to spring 2006 that reported empirical research findings. The focus of our technology integration literature search and discussion in this paper is on the general barriers affecting the use of computing devices in K-12 schools for instructional purposes, and the strategies to overcome those barriers. We looked for a mixture of empirical studies that were conducted in the United States and countries abroad. Using databases such as Academic Search Premier, ERIC, and PsycARTICLES, and Professional Development Collection, we searched using several combinations of keywords including: "technology," "computer," "Internet," "teacher," and "K-12 school." We also employed the "snowball" method and reviewed the references in the selected articles for additional empirical studies. We eliminated those that pertained only to (a) pre-service teachers, (b) non-empirical descriptions of technology integration programs, (c) literature reviews, and (d) opinion papers. We also excluded studies that discussed the non-instructional purposes of technology such as use of technology for administrative support work (e.g., keeping students' attendance records), and other forms of technology such as instructional radio. Consequently, we examined 48 studies that reported empirical findings. Of these 48 studies, 43 came from peer-reviewed journals (e.g., *American Educational Research Journal*), two came from research reports (e.g., the U.S.A. exemplary technology-supported case studies project), two came from conference presentations (e.g., the American Educational Research Association annual meeting), and one came from a book reporting the results of a 10-year empirical study on technology integration.

We then used the constant comparative method (Lincoln & Guba, 1985) on these studies to derive the barrier and strategy categories. Each empirical study was analyzed to identify the types of research studies being conducted, the barriers, and the strategies (if any) used to address the barriers. These barriers and strategies were then subsequently grouped into a number of tentative categories. Every subsequent new barrier or strategy identified was compared to the existing categories, with specific barriers and strategies being recoded as the definitions and properties of each category became better developed. Data analysis continued until the barrier and strategy categories were saturated, meaning that additional data began to confirm the categories rather than identify new categories.

Barriers of technology integration

A total of 123 barriers were found from the review of past empirical studies. In order to provide a coherent and parsimonious description of the various technology integration barriers, we classified them into six main categories: (a) resources, (b) knowledge and skills, (c) institution, (d) attitudes and beliefs, (e) assessment, and (f) subject culture. These barriers are listed in order of the relative frequency in which they were mentioned in the studies reviewed (see Fig. 1).

Resources

The lack of resources may include one or more of the following: (a) technology, (b) access to available technology, (c) time, and (d) technical support. Lack of technology includes insufficient computers, peripherals, and software (e.g., Karagiorgi, 2005; O'Mahony, 2003; Pelgrum, 2001; Sandholtz, Ringstaff, & Dwyer, 1997). Without adequate hardware and software, there is little opportunity for teachers to integrate technology into the curriculum. Even in cases where technology is abundant, there is no guarantee that teachers have easy access to those resources. Access to technology is more than merely the availability of technology in a school; it involves providing the proper amount and right types of technology in locations where teachers and students can use them (Fabry & Higgs, 1997). For example, Selwyn (1999) found that the best

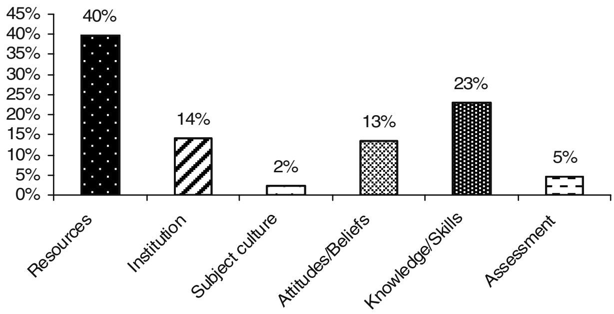

Fig. 1 Relative frequency in which the barriers were mentioned in the past studies

resources tended to be dominated by technology classes (e.g., computer studies); thus resulting in a "pecking order" of subjects where use of computer laboratories is concerned, putting teachers of non-technological subjects (e.g., art, humanities) at a disadvantage. Zhao, Pugh, Sheldon, and Byers (2002) similarly found that although schools have computers housed in laboratories, teachers might not have easy access to them if they needed to compete with other teachers for laboratory time.

Lack of time is another resource-type barrier (Butzin, 2001; Cuban et al., 2001; Karagiorgi, 2005; O'Mahony, 2003). Teachers needed hours to preview web sites, to locate the photos they required for the multimedia project they assigned to students, or to scan those photos into the computers. Teachers who were willing to work longer hours paid a personal price in "burn out" and an eventual exit from the school. The lack of technical support is yet another resource-type barrier (Lai, Trewen, & Pratt, 2002; Rogers, 2000). Teachers need adequate technical support to assist them in using different technologies. Employing a limited number of technical support personnel in a school severely hinders teachers' technology use. More often than not, these technical support personnel were often overwhelmed by teacher requests, and could not respond swiftly or adequately (Cuban et al., 2001).

Knowledge and skills

The lack of specific technology knowledge and skills, technology-supported-pedagogical knowledge and skills, and technology-related-classroom management knowledge and skills has been identified as a major barrier to technology integration. Lack of specific technology knowledge and skills is one of the common reasons given by teachers for not using technology (Snoeyink & Ertmer, 2001/2; Williams, Coles, Wilson, Richardson, & Tuson, 2000). For example, in a study of Scottish schools, Williams et al. (2000), found that lack of skills in the use of databases and spreadsheets was seen as an inhibiting factor by more than 10% of elementary school teachers. Snoeyink and Ertmer (2001/2), in their study of one middle-class school in the United States, also found that limited computer knowledge or skills contributed to the lack of technology integration by teachers. The teachers in their study did not attempt any technology-related activities with their students until they had developed basic skills such as logging onto the network, opening and closing files and applications, and basic word processing.

In addition to the lack of technology knowledge and skills, some teachers are unfamiliar with the pedagogy of using technology. According to Hughes (2005), teachers need to have a technology-supported-pedagogy knowledge and skills base, which they can draw upon when planning to integrate technology into their teaching. Technology-supported-pedagogy may be classified into three categories in which technology functions as: (a) replacement, (b) amplification, or (c) transformation (Hughes, 2005). Technology as replacement involves technology serving as a different means to the same instructional goal. For example, a teacher could type a poem on a PowerPoint slide and project it on the wall. This activity replaces the writing of the poem on a poster and taping it on the wall with the unchanged instructional goal for students to read the poem. Technology as amplification involves the use of technology to accomplish tasks more efficiently and effectively without altering the task (Pea, 1985). For example, a teacher may ask students to edit peers' stories typed in a word processor. As opposed to hand-written stories, the author's ability to easily revise the story based on peers' comments is amplified because the student does not have to rewrite the story each time to accommodate the peers' feedback. Finally, use of technology as transformation has the potential to provide innovative educational opportunities (Hughes, 2005) by reorganizing students' cognitive processes and problem-solving activities (Pea, 1985). For example, students can use computer databases and graphing software as tools for exploratory data analysis, data organization, and for framing and testing hypotheses related to the data. Many teachers have not been exposed to transformative technology-supported-pedagogy because professional development activities have focused primarily on how to merely operate the technology.

The lack of technology-related-classroom management knowledge and skills is another barrier to technology integration into the curriculum. Traditionally, classroom management includes "the provisions and procedures necessary to establish and maintain an environment in which instruction and learning can occur and the preparation of the classroom as an effective learning environment" (Fraser, 1983, p. 68). Classroom management has been identified as the most important factor influencing student learning (Wang, Haertel, & Walberg, 1993).

Typically, traditional classroom management involves a set of guidelines for appropriate student behaviors (Lim et al., 2003). Although the rules and procedures established in a non-technology integrated classroom can apply in a technology-integrated one, there are additional rules and procedures to be established in the latter due to the inclusion of computers, printers, monitors, CD-ROMs, and other technology resources (Lim et al., 2003). Thus, in a technology-integrated classroom, teachers need to be equipped with technology-related classroom management skills such as how to organize the class effectively so that students have equal opportunities to use computers, or what to do if students run into technical problems when working on computers. Examples of empirical evidence indicating that the lack of technology-related-classroom management skills inhibits technology integration can be found in studies conducted by Lim et al. (2003) and Newhouse (2001).

Institution

Institutional barriers may include: (a) leadership, (b) school time-tabling structure, and (c) school planning. Research has shown that school leadership can hinder the integration of technology by teachers. Fox and Henri (2005) found that the majority of Hong Kong teachers felt that their principals did not understand technology and its relevance to the government's proposed shift to more learner-centered activities. Consequently, the impact of technology on the teachers' practices in the classroom was restricted. An inflexible timetable can also act as a barrier. In a survey of more than 4,000 teachers in over 1,100 schools in the United States, Becker (2000) found that most secondary students have a continuous block of less than one hour's duration to do work in any one class. Such a time limit constrains the variety of learning modalities their teachers can design. Consequently, fewer teachers plan computer activities on a regular basis. The lack of school planning with regard to technology use is another barrier. Lawson and Comber (1999) found that in one United Kingdom school that made minimal use of technology, the administrators had decided to enter a technology integration project as a way of getting free Internet access for a year. There had been no planning regarding what to do with the technology once it was installed, and the administrators left the information technology department to its own devices during the project. Consequently, the use of technology did not extend beyond that department.

Attitudes and beliefs

Teacher attitudes and beliefs towards technology can be another major barrier to technology integration (Hermans, Tondeur, Valcke, & Van Braak, 2006). According to Simpson, Koballa, Oliver, and Crawley (1994), attitudes can be defined as specific feelings that indicate whether a person likes or dislikes something. In the context of technology integration, teacher attitudes toward technology may be conceptualized as teachers liking or disliking the use of technology. Beliefs can be defined as premises or suppositions about something that are felt to be true (Calderhead, 1996; Richardson, 1996). Specifically, teachers' beliefs may include their educational beliefs about teaching and learning (i.e., pedagogical beliefs), and their beliefs about technology (Ertmer, 2005; Windschitl & Sahl, 2002). Researchers have found that beliefs determine a person's attitude (Bodur, Brinberg, & Coupey, 2000).

Ertmer (2005) argued that the decision of whether and how to use technology for instruction ultimately depends on the teachers themselves and the beliefs they hold about technology. For example, in an investigation of one elementary school in the United States, Ertmer, Addison, Lane, Ross, and Woods (1999) found that teachers' beliefs about technology in the curriculum shaped their goals for technology use. Teachers who viewed technology as merely "a way to keep kids busy," did not see the relevance of technology to the designated curriculum. Computer time was commonly granted after regular classroom work was done and as a reward for the completion of assigned tasks. To these teachers, other skills and content knowledge were more important. Similarly, other researchers have found teacher beliefs about technology to be a major barrier to technology integration. For example, a study in Australia that investigated the perceptions of students and teachers towards the use of portable computers at a secondary school revealed that the majority of teachers believed that computers would not lead to better understanding or faster learning (Newhouse, 2001). Similarly, teachers in

Cyprus who participated in a program focusing on information and communication technologies in schools, failed to see the value of such technology for their students. Although they had seen the power of the computer in other areas, they were unconvinced that it could help in education (Karagiorgi, 2005).

Assessment

Assessment can be defined as the activity of measuring student learning (Reeves, 2000). It can be formative or summative in nature, although traditionally, it is typically summative in the form of school and national high-stakes testing. High-stakes testing can be defined as assessment with serious attached consequences such as promotion or graduation for students (CEO Forum on Education and Technology, 2001) or rewards versus sanctions for schools. The pressures of such testing can be a major barrier to technology integration. For example, Fox and Henri (2005) explored the use of technology in Hong Kong elementary and secondary school classrooms and found that pressures related to high-stakes testing gave teachers little time to attempt new instructional methods involving technology. This view was corroborated by Butzin (2004) who noted that the pressure to meet higher standards and score high on standardized tests, along with the need to cover vast scope of material within a limited amount of time, creates a daunting challenge for any teacher. Consequently, teachers feel they can cover more material when they are in front of the class talking with every student doing the same thing at the same time, rather than using technology because of the additional technology planning time required to identify and select appropriate software to match lesson objectives (Butzin, 2004).

In addition, high-stakes testing can result in the shift of using technology from teaching and learning to using it to facilitate assessment (Bichelmeyer, 2005). The ‘‘No Child Left Behind’’ act has placed great emphasis on testing and has accordingly drawn more attention to comparative test scores (Brantley-Dias, Calandra, Harmon, & Shoffner, 2006). Such emphasis on testing, argued Schneiderman (2004), undercuts the potential promise of technology as a teaching and learning tool. As a result, the focus of technology use in K-12 education has not been on the use of computers for teaching and learning, but rather on the financial benefits of computer-based testing and the warehousing of assessment results (Bichelmeyer & Molenda, 2006; Education Week, May 8, 2003).

Finally, Hennessy et al. (2005) found that there was a perceived tension between using technology and the need to conform to the external requirements of traditional examinations. Requirements to use technology to enhance learning without recognition through assessment were deemed problematic. For example, there was concern that the use of graphic calculators was disadvantageous to students because such calculators are prohibited in national examinations. Such concerns led to decreased enthusiasm among teachers for using technology.

Subject culture

Subject culture refers to the ‘‘general set of institutionalized practices and expectations which have grown up around a particular school subject, and shapes the definition of that subject as a distinct area of study’’ (Goodson & Mangan, 1995, p. 614). Subject cultures have long-standing histories, reinforced by generations of school practice (Goodson & Mangan, 1995), and are typically shaped by the subject content, subject pedagogy, and subject assessment (Selwyn, 1999). Teachers are reluctant to adopt a technology that seems incompatible with the norms of a subject culture (Hennessy, Ruthven, & Brindley, 2005). For example, Selwyn (1999) found an art teacher who justified her avoidance of using computers by saying that when painting, one would be more in tune with it if one did it physically with one’s own hand; the art teacher believed that using a mouse makes one’s mind and hand disjointed. Another art teacher argued that from an aesthetic point of view, accessing art galleries through a computer can never equal experiencing an actual painting in person.

Identifying the relationships among the barriers

Although each type of barrier was described separately, in reality the barriers are related to one another. In this section, we construct a tentative model based on the findings of past studies to describe such relationships (see Fig. 2). The linkages shown in Fig. 2 denote claims made by the studies that certain barriers can influence others. For example, Selwyn (1999) and Hennessy et al. (2005) claim that assessment influences subject cultures. It can be seen from

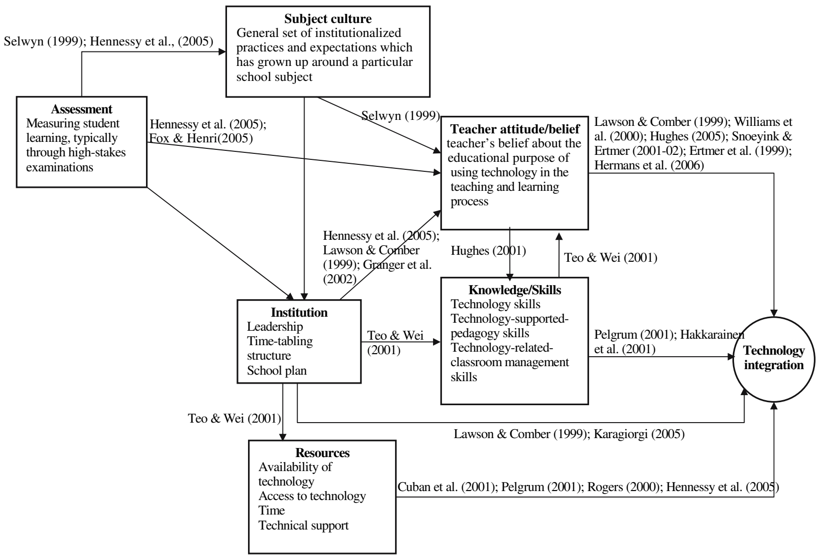

Fig. 2 Model showing the relationships among the various barriers

Fig. 2 that technology integration is thought to be *directly* influenced by the following four barriers: (a) the teacher's attitudes and beliefs towards using technology, (b) the teacher's knowledge and skills, (c) the institution, and (d) resources. Teachers' attitudes and beliefs toward using technology are also thought to be affected by their knowledge and skills, and vice-versa. In addition, the institution appears to directly affect the adequacy of resources provided for technology integration, the adequacy of teachers' knowledge and skills (via provision of professional development), and teachers' attitudes toward using technology. For example, Hennessy et al. (2005) found that an institution's top-down internal policies to use technology within subject teaching could cause a feeling of disempowerment in teachers. Teachers interviewed felt that they had to include technology into schemes of work, regardless of whether technology was particularly useful for that aspect of the curriculum.

Technology integration is also thought to be *indirectly* influenced by the subject culture and assessment. Subject culture indirectly affects technology integration via teachers' attitudes and beliefs, and the institution. The latter is affected because an institution is made up of various subject departments that are inexorably linked with their respective subject cultures (e.g., arts department with the arts subject culture). Although technology may be integrated more routinely in certain subjects such as geography and business studies (Selwyn, 1999), its use is still affected by the mode of assessment. Assessment indirectly affects technology integration because the form of assessment typically dictates both how a subject should be taught and assessed and thus how technology should be used (e.g., the use of graphing calculators is not encouraged because they are prohibited in high-stakes testing).

Having described the general barriers typically faced by K-12 schools when integrating technology into the curriculum for instructional purposes, we now describe the strategies to overcome the barriers in the following section.

Strategies to overcome barriers

In order to provide a coherent description of various strategies to overcome barriers, we have classified them into five main categories: (a) having a shared vision and technology integration plan, (b) overcoming the scarcity of resources, (c) changing attitudes and beliefs, (d) conducting professional development, and (e) reconsidering assessments. These strategies are not listed in order of priority or importance. Table 1 summarizes all the five categories of strategies.

Having a shared vision and technology integration plan

Having a shared vision of learning and teaching can serve as a driving force for overcoming leadership barriers to technology use (Sandholtz et al., 1997; Tearle, 2004). Lim and Khine (2006), for example, found in their study of four

Table 1 Summary of strategies to overcome barriers of technology integration

Barriers	Strategies
Resources	*Obtaining the necessary resources*
• Lack of technology	• Introduce technology into one or two subject areas at a time to ensure that teachers and students in those areas have adequate technology and access to technology (Tearle, 2004) • Create a hybrid technology setup in classrooms that involved cheaper computer systems. (Sandholtz & Reilly, 2004) • Use laptops with wireless connections to save building and maintenance costs of the computer laboratories (Lowther et al., 2003)
• Lack of access to technology	• Putting technology into the classrooms rather than in centralized locations (Becker, 2000) • Rotate students through the small number of classroom (Sandholtz et al., 1997)
• Lack of time	• Teachers collaborate to create technology-integrated lesson plans and materials (Dexter & Anderson, 2002; Lim & Khine, 2006) • Reduce class loads for teachers in order to free up some school time (Snoeyink & Ertmer, 2001–2002). For example, reduce the overall curriculum content (MOE Singapore, 1998) • *Also include the strategy for time-tabling structure*
• Lack of technical support	• Use student technology helpers (Cuban et al., 2001; Lim et al., 2003)
Institution	*Shared vision and technology plan*
• Leadership	• Having a shared vision (Rogers, 2000; Sandholtz et al., 1997; Tearle, 2004; Yuen et al., 2003)
• Time-tabling structure	• Schools change their time-tabling schedule to increase class time to double period sessions (Bowman et al., 2001)
• Lack of technology integration plan	• Having a technology plan (Fishman & Pinkard, 2001; Lawson & Comber, 1999). Such a plan should center on teaching and learning, not merely on technology issues (Rogers, 2000)
Subject culture	• *No strategies currently mentioned in the studies reviewed*
Attitudes/beliefs	*Facilitating attitudes/beliefs change* • Institution support (having vision and plan; providing the necessary resources; providing ongoing professional development; encouraging teachers) (Lawson & Comber, 1999; Sandholtz & Reilly, 2004; Granger et al. 2002; Teo & Wei, 2001) • Subject culture • Assessment (*see strategies for assessment below*) • Professional development (*see strategies for professional development below*)
Skills	*Professional development* – have three essential overlapping facets: (a) appropriate to the needs of the teachers and classroom practice, (b) provides opportunities for teachers to engage in active learning, and (c) focuses on: technological knowledge/skills, technology-supported pedagogy knowledge/skills, and technology-related classroom management knowledge/skills.
• Lack of technology skills	• Provide basic technology knowledge/skills training (Mulkeen, 2003; Snoeyink & Ertmer (2001–2002)
• Lack of technology-supported-pedagogy skills	• Ground learning experiences in content-connected technology examples (Hughes, 2005). Can be achieved through the use of a buddy system approach (Lim & Khine, 2006)

Table 1 continued

Barriers	Strategies
• Lack of technology-related-classroom management skills	• Establishment of rules and procedures (Lim et al., 2003). • Classroom layout redesign (Zandvliet & Fraser, 2004)
Assessment	*Assessment* • New ways to assess students' multimedia work. For example, a contract that indicates how many slides would be produced, and evidence of how the information was obtained (Bowman et al., 2001) • Closely aligning the technology to their state's curriculum standards (Dexter & Anderson, 2002)

schools that a shared vision and technology integration plan gave school leaders and teachers an avenue to coherently communicate how technology can be used, as well as a place to begin, a goal to achieve, and a guide along the way. Without such a vision, it is likely that teachers and administrators will limit their thinking about technology to ‘‘boxes and wires’’ or isolated computer skills (Fishman & Pinkard, 2001, p. 70). Probably the most important issue to consider when formulating a shared vision regarding technology integration is to address the specific relationship between technology and particular curriculum content areas because a commitment to the curriculum is a critical scaffold for technology integration (Staples, Pugach, & Himes, 2005). In other words, the vision for technology integration should be to enhance student learning of the curriculum (Staples et al., 2005). It is also important to note that the vision should not be created by just the school leaders; teachers, in particular, should be involved in the decision-making because teacher participation has been found to be one of the ingredients for successful wide-scale integration of technology in a school district (Bowman, Newman, & Masterson, 2001; Eshet, Klemes, Henderson, & Jalali, 2000).

After a vision has been successfully created and accepted, the next step is to articulate a technology integration plan, which provides a detailed blueprint of the steps needed to translate the school technology vision into reality. Fishman and Pinkard (2001) offered some practical advice on how to facilitate the development of a technology integration plan: establish a ‘‘planning for technology’’ committee that consists of teachers, administrators, and outside facilitators (e.g., educational technology experts) who are willing to help facilitate change. The outside facilitators can help to address any questions that teachers and administrators may have.

In a study of one school in Turkey, Gülbahar (in press), found several issues that were deemed necessary to be considered during the actual development of a technology integration plan. These issues relate to the maintenance and regular upgrade of the technology resources, equity of access to technology for teachers and students, a reward or recognition system that encourages teachers' use of technology, and professional development opportunities to teachers. Another issue that needs to be considered is the expectations of technology use for instructional purposes such as the stipulated number of technology-mediated lessons to be conducted per week (Lim & Khine, 2006). Stipulating the number of technology-integrated lessons can serve as a tool to exert pressure on teachers to use technology and thereby to increase usage (O'Dwyer, Russell, & Bebell, 2004). Other forms of pressure that had been found useful for technology integration involve the expectation for teachers to participate in team meetings regarding use of technology, and requiring the scope for technology use to be developed for all grade and skill levels (Schiller, 2002). Another issue to be considered in the technology plan is the formulation of monitoring activities to ensure that technology integration is taking place. Examples of monitoring activities used by principals that were found to be significant in ensuring teachers' use of technology include: one-on-one discussions with teachers, observation visits to classrooms, and scrutiny of lesson and program plans (Schiller, 2002).

Overcoming the scarcity of resources

Three strategies to overcome the *lack of technology* barrier were reported in previous studies. First, create a hybrid technology setup in classrooms that involved cheaper computer systems, such as "thin client computers." Thin client computers consist of only a monitor and a device that provides access to a network with no hard or floppy drive. These computers can be purchased at one third the cost of a traditional personal computer. In their study of a U.S. K-8 public school district, Sandholtz and Reilly (2004) found that the use of thin client computers provided three distinct advantages: (a) their lower cost enabled schools to stretch their purchasing capacity, (b) the thin clients presented few maintenance or technical problems for teachers to address, and (c) thin clients reduced space management issues due to their small size. Second, introduce technology into one or two subject areas at a time to ensure that teachers and students in those areas have adequate technology (Tearle, 2004). Third, instead of building expensive computer laboratories and equipping them with desktop computers, use laptops with wireless connections to achieve a one-to-one student-to-computer ratio (Lowther, Ross, & Morrison, 2003). Using laptops can save building and maintenance costs of the computer laboratories. Furthermore, there is evidence that laptops can provide potentially optimal contexts for integrating technology use into teaching practices (Lowther et al., 2003). Laptops can either be provided to students on a permanent or temporary one-to-one basis. One possible way to achieve a temporary one-to-one student-to-laptop ratio is to use mobile laptop carts (Grant, Ross, Wang, & Potter, 2005; Russell, Bebell, & Higgins, 2004). The mobile laptop carts can be brought from one classroom to another on an as-needed basis.

Overcoming the *lack of access to technology* barrier can involve two strategies. First, several computers could be placed in the classroom, rather than in centralized locations. For example, Becker (2000) found that secondary subject teachers who have five to eight computers in their classroom were twice as likely to give students frequent computer experience during class as their counterparts whose classes used computers in a shared location. Explaining this paradox, Becker said that the need for scheduling whole classes to use computers as in the case of centralized or shared locations makes it nearly impossible for technology to be integrated as research, analytic, and communicative tools in the context of the work of an academic class. The use of laptops or mobile laptop carts can also eliminate the inconvenience of scheduling class time since the laptops can be brought to class to achieve a one-to-one student-to-computer ratio (Lowther et al., 2003). The second strategy for overcoming the lack of access to technology is to rotate students in groups (e.g., cooperative learning) (Johnson & Johnson, 1992) through the small number of computers in the classrooms. In such classrooms, the teachers employ a station approach using various learning activities (e.g., reading centers, computer centers, etc.). Groups of students then take turns rotating through each learning center; thus ensuring that each one has an opportunity to use the computers (Sandholtz et al., 1997).

To overcome the *lack of time* barrier, three strategies were identified from our review of empirical studies. First, schools can change their time-tabling schedule to increase class time to double period sessions (Bowman et al., 2001). Becker (2000) found that secondary school teachers who work in schools with schedules involving longer blocks of time (e.g., 90–120 min classes) were more likely to report frequent use of technology during class compared to teachers who taught in traditional 50-minute periods. Second, class loads for teachers can be reduced in order to free up some school time for teachers to familiarize themselves with technology and develop appropriate technology-integrated curricula activities (Snoeyink & Ertmer, 2001–2002). One way to decrease class loads is to reduce the overall curriculum content. For example, since 1998 the Ministry of Education in Singapore has achieved a 10–30% content reduction in almost all curriculum subjects at the secondary school level without compromising on basic foundation knowledge that students need to master to proceed to higher levels of education (MOE Singapore, 1998). Third, teachers should be encouraged to collaborate to create technology-integrated lesson plans and materials (Dexter & Anderson, 2002; Lim & Khine, 2006). By working together, teachers are able to shorten the time needed to produce technology-integrated lessons as compared to producing the lessons alone.

To overcome the *lack of technical support*, students can be trained to handle simple hardware and software problems rather than employing many professional technicians. Thus, paying technicians would be necessary only when the hardware or software problems are beyond the students' abilities to remedy. This can be a more cost-effective way than employing many full time professional technicians. Lim et al. (2003) found the use of student helpers an effective way to relieve some of the technical problems that may occur in a technology-integrated lesson, so that the teacher could focus more attention on conducting and managing instructional activities.

Changing attitudes and beliefs

To facilitate change in attitudes and beliefs, the current review has suggested that four factors need to be taken into consideration: teachers' knowledge and skills, subject culture, assessment, and institution support. Institution support typically comes in four major ways: (a) having a vision and plan of where the school wishes to go with technology (e.g., Lawson & Comber, 1999); (b) providing necessary resources for teachers (e.g., Sandholtz & Reilly, 2004); (c) providing ongoing professional development for teachers (e.g., Schiller, 2002; Teo & Wei, 2001); and (d) providing encouragement for teachers (e.g., Granger, Morbey, Lotherington, Owston, & Wideman, 2002; Mouza, 2002–2003).

Granger et al. (2002), in their study of four schools in Canada, found that teachers stressed the importance of principals providing encouragement for teachers by acting as advocates in a period of fiscal restraint and ever-increasing demands on educators. As one teacher said, "[The] atmosphere is very relaxed with administrators who give you an opportunity to basically experiment and explore and you don't have to be perfect...[it] allows us to be risk takers, to make mistakes..." (p. 485). Another teacher noted that good leadership is "being allowed to do your own thing with encouragement to improve" (p. 486). These findings support the notion that school leaders should not take teachers immediately to task for any mistakes that teachers may make, especially when they are new to technology.

Given that teachers need encouragement when integrating technology, how then can principals' support be increased? One possibility is to help principals develop an appreciation for technology so that they can be more understanding of what teachers experience when they integrate technology in their lessons (e.g., teachers' anxieties and struggles). Such understanding is likely to be fulfilled by providing principals with technology training, particularly exposure to methods and procedures of integrating technology into the curriculum (Dawson & Rakes, 2003).

Providing professional development

Professional development can influence a teacher's attitudes and beliefs towards technology (Shaunessy, 2005; Teo & Wei, 2001), as well as provide teachers with the knowledge and skills to employ technology in classroom practice (Fishman & Pinkard, 2001). In an empirical study of the effects of different characteristics of professional development on a national sample of over 1,000 teachers, Garet, Porter, Desimone, Birman, and Yoon (2001) found that both traditional and innovative types of professional development of the same duration tend to have the same effects on reported outcomes. They concluded on this basis that it is more important to focus on the *features* of professional development rather than its *types* (i.e., innovative types versus traditional types such as study groups or mentoring versus formal training workshops or conferences). Following this recommendation, we focused specifically on features that made professional development effective.

A review of relevant literature shows that effective professional development related to technology integration: (a) focuses on content (e.g., technology knowledge and skills, technology-supported pedagogy knowledge and skills, and technology-related classroom management knowledge and skills), (b) gives teachers opportunities for ‘‘hands-on’’ work, and (c) is highly consistent with teachers’ needs. First, focusing on technology knowledge and skills is clearly important because technology integration cannot occur if the teacher lacks the knowledge or skills to operate computers and software. Snoeyink and Ertmer (2001–2002) found that teachers did not see the value of technology integration until they had developed basic skills such as logging onto the network and basic word processing.

Teachers also need to have the necessary technology-supported pedagogy knowledge and skills in order to integrate technology for instructional purposes (Dexter & Anderson, 2002; Mulkeen, 2003). In her study of four English language arts teachers, Hughes (2005) found that the power to develop technology-supported pedagogy lies in the teacher’s interpretation of the technology’s value for instruction and learning in the classroom. The most effective method toward this end, claimed Hughes, is helping teachers to see a clear connection between the technology being used and the subject content being taught—what Hughes referred to as ‘‘learning experiences grounded in content-based technology examples’’ (p. 277). As Hughes put it, ‘‘It accords that the more content-specific the example, the more likely the teacher will see the value [of technology] and learn it’’ (p. 296). For example, a novice teacher can observe a more knowledgeable colleague using technology in a content-specific area (e.g., use of PowerPoint to teach the structure of English Language and composition). Teachers also need to understand the unique aspects of preparing lessons that use technology, for example, having tight definition of tasks involving the use of the Internet. Such teacher actions were found to contribute towards successful lessons with technology (Rogers & Finlayson, 2004). Teachers, for example, need to recognize the balance between the advantages of giving students responsibility and the potential unproductiveness of random surfing on the Internet. Successful solutions employed by the teachers in Rogers and Finlayson’s (2004) study involved use of limited ranges of website addresses, clear deadlines, and encouragement to students to develop their critical skills about the nature and quality of information obtained.

Effective professional development also focuses on technology-related classroom management knowledge and skills. Sandholtz et al. (1997) noted that in every classroom, events typically take unexpected directions. The changes in a classroom environment caused by the addition of technology often lead to an even higher level of unpredictability. One way to help manage unpredictability is to establish clear rules and procedures for technology usage (Lim et al., 2003). Some of these rules included the following: (a) no unauthorized installation of programs and (b) no unauthorized change to the features of the computer control panel. Some of the procedures included: (a) indexing the computers with the index number of the student to facilitate student seat assignment and enable the teacher to track down the student who abused the computer, and (b) pairing students with stronger technology skills with those who needed more support using technology to reduce the need for students to frequently interrupt the teacher for help.

Classroom layout redesign is another strategy to help teachers manage technology-integrated classroom. For example, Zandvliet and Fraser (2004) found that room layouts could either promote or restrict the technology-integrated activities performed in those settings. The researchers found that teachers consistently preferred peripheral-type layouts (characterized by computer workstations positioned along the wall of a room) because such layouts allowed teachers to monitor student work to ensure that the students were constantly engaged in the learning tasks while using the computers. Students also preferred this type of layout as it allowed easy movement and interaction among them as they worked on their projects or assignments.

Second, effective professional development provides teachers with opportunities for active learning. Active learning can take a number of forms, including the opportunity to observe expert teachers in action (Garet et al., 2001). One possible method for novice teachers to observe expert teachers in action is through the use of a "buddy system" strategy where novice teachers work together with expert teachers in a classroom using technology (Lim & Khine, 2006). For example, a novice teacher can observe a more knowledgeable colleague using technology in a content-specific area, a strategy that Ertmer (2005) referred to as vicarious experiences.

Third, effective professional development is situated to teachers' needs (Dexter & Anderson, 2002; Keller, Bonk, & Hew, 2005). Granger et al. (2002) found that "just-in-time" professional development is the most influential factor contributing to teachers' integration of technology into their classrooms. "Just-in-time" professional development, rather than "just-in-case" development (Schrum, 1999) may gain more teacher acceptance because it addresses the teachers' immediate concerns and is thus consistent with teachers' needs (Granger et al., 2002). This need-to-know approach to constructing technology knowledge and skills can transform teachers into active knowledge builders possessing substantial autonomy regarding the specific skills required (Granger et al., 2002). An example of how professional development for in-service K-12 teachers can build upon the tenets of situative learning perspectives has been provided by Keller et al. (2005).

Reconsidering assessment

Because curriculum and assessment are closely intertwined, there is a need to either completely reconsider the assessment approaches when technology is integrated into the school curriculum, or consider more carefully how the use of technology can meet the demands of standards-based accountability. To address the former, alternative modes of assessment strategies may be formulated. For example, Bowman et al. (2001) found that one teacher created a contract with students detailing what they were expected to submit as part of their final grade. The contract indicated how many PowerPoint slides would be produced and evidence of how the information was obtained. Other teachers developed protocols for creating electronic portfolios of student work that would be evaluated and assessed during the school year.

Although the use of alternative modes of assessment is a possible strategy, there is still a need to consider how technology can be used to meet the current demands of standards-based accountability. Dexter and Anderson (2002) provided some examples of how schools can achieve this, mainly by closely aligning the technology to their state's curriculum standards. Newsome Park Elementary School, for instance, had received a warning from its state department of education concerning its students' low scores related to the Standards of Learning (SOL). The school then made it a major priority to align the district's curricular content and requirements and its use of technology to the state's SOLs. Specifically, the school decided to implement technology-supported project-based learning using wireless laptops through three distinct phases: planning, fieldwork, and celebration of learning. For example, in the planning phase, students brainstormed, under the teachers' guidance, the specific questions they wanted to answer. The teachers then planned how they could address the SOLs through the students' project work. Anderson and Dexter (2003) reported that teachers were pleased to find that they could let the students set the direction (hence increased students' motivation toward learning) and still be able to make significant gains on the state's SOL examinations, indicating that technology-supported project-based learning might have played a key role in the improvement of student outcomes.

Current knowledge gaps and recommendations for future research

Based on the analysis of related research, we now discuss several current knowledge gaps and provide recommendations for future research related to barriers and strategies of integrating technology for instructional purposes. In discussing these current knowledge gaps, it is useful to adopt Ertmer's et al. (1999) notion of first- and second-order barriers to achieve a more parsimonious classification of the barriers. First-order barriers are obstacles that are external to teachers; while second-order barriers are intrinsic to teachers (Ertmer et al., 1999). This notion can also be extrapolated to strategies (Table 2).

Table 2 First- and second-order barriers and strategies*

	Barrier	Strategy
First-order	• Lack of resources • Institution • Subject culture • Assessment	• Creating a shared vision and technology integration plan • Obtaining the necessary resources • Having alternative modes of assessments
Second-order	• Attitudes and beliefs • Knowledge and skills	• Facilitating attitude change • Facilitating teacher knowledge and skills

* Adapted from Ertmer et al. (1999)

Barriers

The first knowledge gap is associated with the relationships between the first- and second-order barriers: How much do we exactly know about how first- and second-order barriers interact and influence each other in hindering the integration of technology for instructional purposes? In the present literature review, the study by Ertmer et al. (1999) was unique in that examined the relationship between the two classifications of barriers in more detail rather than merely highlighting that the barriers are related to one another. Many researchers have thought that second-order barriers cause more difficulties than the first-order ones (e.g., Ertmer, 1999; Ertmer et al., 1999). The danger of this assumption is that educators and administrators may be led to assume that overcoming second-order barriers is enough. As noted by Zhao et al. (2002), there are ''serious problems with the current effort to prepare teachers to use technology. Most of the current efforts take a very narrow view of what teachers need to use technology—some technical skills and a good attitude'' (p. 511). Having technical skills and a good attitude might help to overcome second-order barriers. However, Fig. 1 suggests that second- and first-order barriers are so inextricably linked together that it is very difficult to address them separately. For example, trying to change teachers' attitudes and beliefs (a second-order barrier) toward using technology is likely to be futile in the long run if one does not seriously consider changing the way students are currently assessed through current high-stakes national examinations (a first-order barrier) that discourage using technology during the assessment. Future research should therefore examine the relationships between the first- and second-order barriers in greater detail. For example, how valid are the relationships among the various barriers shown in Fig. 1? How do these relationships change over time? Future research should also investigate other barriers that may need to be considered, especially a when one-to-one student to computer ratio is achieved.

It would also be useful to compare and contrast our model shown in Fig. 1 with other existing models. For example, in Rogers' (2000) model, six main barriers are shown: (a) stakeholder attitudes and perceptions, (b) stakeholder development, (c) availability and accessibility of technology, (d) technical support, (e) funding, and (f) time. All Rogers' (2000) barriers are represented in our model, with the exception of ''funding.'' The lack of funding was not highlighted in our model because it was not explicitly mentioned in the studies we reviewed. Perhaps this is due to lack of funding being implicitly expressed in the barriers already mentioned (e.g., lack of technology, lack of technical support, or lack of professional development).

There is also a need for research to examine specific barriers of technology integration in greater detail. We highlight the barrier of teacher beliefs in our discussion. As previously mentioned, teachers' beliefs may include their educational beliefs about teaching and learning (i.e., pedagogical beliefs), and their beliefs about technology. Making the distinction between beliefs and knowledge, Ertmer (2005) considers teacher pedagogical beliefs as the final frontier in our quest for technology integration because of the assumption that beliefs are far more influential than knowledge in predicting teacher behavior due to the stronger affective components often associated with beliefs (Nespor, 1987). Other scholars, however, disagree. Baker, Herman, and Gerhart (1996), for example, suggested that teachers' content knowledge and pedagogical knowledge are the prime influence on whether and how teachers use technology. Perhaps the appropriate question to address with regard to this disagreement is under what conditions beliefs and knowledge will exert the main influence on teachers' use of technology. Research conducted in other settings showed that knowledge can be a better predictor than beliefs with regard to certain tasks (e.g., predicting the studying behavior of undergraduate students) (Trafimow & Sheeran, 1998).

With regard to teachers' beliefs about technology, there is a need to develop clear operational definitions of such beliefs. Currently, different researchers view teacher beliefs about technology differently—thus complicating efforts by researchers and educators to interpret the findings across studies. For example, Ertmer et al. (1999) view teacher beliefs about technology primarily in relation to the *curriculum*. For example, is technology used to reinforce skills, enrich current topics, or extend topics beyond current levels? O'Dwyer, Russell, and Bebell (2004), on the other hand, consider teacher beliefs about technology to whether it can harm *students* (e.g., computers have weakened students' research skills), or benefits students (e.g., computers help student grasp difficult concepts).

Integration strategies

The second knowledge gap is related to the relationships between the strategies. Research has shown that successful technology integration requires a holistic approach that addresses both first- and second-order strategies (Dexter & Anderson, 2002; Eshet et al., 2000). Zhao et al.'s (2002) study, for example, investigated factors needed for classroom technology integration, revealing that factors or strategies related to the teacher, the technology project, and the school context were interrelated. Interestingly, the researchers found that second-order factors associated with the teacher (e.g., teachers' knowledge and skills of the broader computing system requirements associated with the use of a specific technology), appeared to play a *more* significant role in contributing to classroom technology integration efforts than other factors such as having access to technological infrastructure, or support from peers. Future research should be conducted to examine this claim.

There is also a crucial need to learn more about certain strategies. We highlight two in our discussion: subject culture and assessment, and technology integration plan. We concur with Hennessy et al. (2005) that hitherto little research has been conducted to examine how and why subject cultures affect the use of technology. Studies by Goodson and Mangan (1995), Hennessy et al. (2005), and Selwyn (1999) were the three exceptions that attempted to provide more detailed analysis and discussion of the reasons underlying why technology use appears to be more biased toward subjects such as business, and design and technology, rather than simply highlighting subject matter differences in technology applications. In short, these studies corroborate the notion that subject cultures can be an important barrier that hinders teachers' use of technology in their teaching. However, none of these studies investigated specific strategies that can be used to overcome subject culture barriers. There is therefore a need for further research to investigate how teachers could use technology specifically in the case that technology is incongruous with a particular subject culture. Interestingly, there is evidence showing that use of technology is not widespread even in subject cultures that appear to be congruous with technology. For example, Williams et al. (2000) found that mathematics and science teachers used technology relatively *less* frequently than teachers of social and aesthetic subjects. However, no explanation was provided by Williams et al. (2000) for the discrepancies found.

In addition, because subject cultures are closely influenced by how students are assessed, future research is needed to examine the use of alternative modes of assessment that can accommodate students' use of technology. Probably the most pressing need is for more research to investigate how the use of technology can fit with the current demands of standards-based accountability.

With regard to technology integration planning, Mulkeen (2003) found that Irish schools that regularly updated their technology plans had significantly more use of technology in subject areas than those that did not. However, nothing was mentioned about the nature and actual frequency of such updates. Further research should be conducted to verify Mulkeen's (2003) findings, as well as address in greater depth the nature of the updates that lead to certain schools having significantly greater uses of technology for instructional purposes.

It is also important to examine the potential drawbacks of each integration strategy. For example, although the strategy of encouraging teachers to collaborate to create technology-integrated lesson plans and materials could help teachers save time (Lim & Khine, 2006), collaboration in itself can be difficult to achieve given that teachers have many other responsibilities to which they need to attend in a school day. Zhao et al. (2002) reported that teachers who were *less* dependent on other teachers (i.e., less reliance on the cooperation, participation, or support of other people) tended to have *greater* success in integrating technology in their classrooms. Similarly, the strategy of having students work cooperatively in groups and rotating them through the small number of classroom computers can itself be difficult to design and deliver effectively (Nath & Ross, 2001). For example, studies indicate caution about the conditions that favor success regarding cooperative group work (Rogers & Finlayson, 2004). In particular, groups must have the ability to organize themselves in ways, which integrate the contributions of all members. How a teacher structures the tasks, organizes, and manages productive cooperative group work in relation to technology use is an area that needs further study. Acknowledging the drawbacks is essential for teachers or school administrators to make informed decisions about the strategies they are considering implementing. Future efforts should therefore be expended in examining the efficacy and feasibility of these strategies (especially over a long period of time), leading perhaps to some empirical-based guidelines as to how these strategies can be optimally employed.

Another point regarding strategies is that none of the previous studies we examined included discussion of findings in relation to past evidence about the integration of a prior technology (e.g., instructional television). Findings from the integration of past technologies, may help today's researchers and educators better understand the factors that can facilitate the integration of current computing devices for instructional purposes. In an attempt to determine if there are any differences between the integration of computing devices and the integration of a past technology into teaching and learning, we examined Chu and Schramm's (1967) work that summarizes the findings of research on instructional television. We found that much of what had been written about strategies (and barriers) for integrating instructional television for instructional purposes were similar to the current strategies (and barriers) for integrating computing devices. For example, strategies such as providing adequate technology planning and time, and training for the classroom teacher were considered important for the integration of instructional television into the curriculum. However, there is one key issue that appears to suggest why despite the barriers (e.g., teacher attitudes and beliefs) instructional television was used widely and effectively in certain quarters. This difference is related to the size and urgency of an educational problem, rather than integration strategy. As Chu and Schramm (1967) stated: ''If the objective is obviously important... it is easier for the classroom teacher to put aside his objections, make his schedule fit, learn the new role. If the objective is not urgent... it is easier for a classroom teacher to drag heels'' (p. 18). Examples of sizeable and urgent problems included the need to teach large number of students in remote areas (e.g., in certain sections of Italy and Japan) where instructional television was the only technology that could be used efficiently. Similarly, perhaps the way that barriers of integrating computing devices for instructional purposes can be overcome is not by examining more strategies but through the occurrence of events that exclude or discourage usage of other media.

Stages of technology integration

The third knowledge gap is related to the barriers and strategies associated with the different stages of technology integration by teachers. Some researchers see technology integration by teachers as an evolutionary process rather than a revolutionary one (Hokanson & Hooper, 2004; Rogers, 2000; Zhao et al., 2002). Hokanson and Hooper (2004), for example, postulated that technology integration occurs along different stages: (a) familiarization, (b) utilization, (c) integration, (d) reorientation, and (e) evolutionary. A survey conducted by Rogers (2000) with 507 art teachers found that certain barriers were more prevalent in certain stages. For example, first-order barriers such as availability and accessibility of technology were most likely to be encountered by teachers at the beginning stages (e.g., familiarization and utilization). Additional research is needed to validate Rogers' findings and conclusions about the barriers in other schools and subjects areas to determine if the findings are typical of all teachers at the beginning stages or strongly dependent on the specific subject areas. Other additional knowledge gaps related to the stage theory of technology integration include the following: (a) it is unclear whether the stages were derived from long-term observations of individual teachers or represented levels that different teachers occupied at a certain point in time, and (b) it is unclear how individual teachers make leaps of progress from one stage to another and the strategies used to help them do so (Windschitl & Sahl, 2002).

One-to-one computing learning environments

The fourth knowledge gap is associated with barriers and strategies in K-12 contexts where every student is provided with a computer for use in the classroom or school (i.e., one-to-one computing learning environments). One-to-one learning environment is typically made possible in a number of ways, including the use of laptops for every student (e.g., Sclater, Sicoly, Abrami, & Wade, 2006; Windschitl & Sahl, 2002), mobile laptop carts (Grant et al., 2005; Russell et al., 2004), or handheld devices (van 't Hooft, Diaz, & Swan, 2004). Since a growing body of literature suggests that a high ratio of computers to students (e.g., laptops for every student) may change the teaching and learning dynamics in the classroom (Garthwait & Weller, 2005), it is possible that one-to-one computing learning environments also introduce new barriers. Hence, new strategies may need to be formulated to overcome these new barriers.

Current studies on laptop integration have largely focused on comparing student achievement scores (e.g., reading scores), student writing and problem solving skills, frequency of technology use, types of activities for which the technology was used (e.g., search the Internet), motivation, or classroom structure between classrooms that had laptops (1:1 student:computer ratio) with classrooms that had several students per computer (e.g., Lowther et al., 2003; Sclater et al., 2006). Other studies examined classrooms that had 1:1 laptops on a permanent basis with those classrooms that shared a mobile cart of laptops on a temporary basis (Russell et al., 2004). Strategies to overcome the barriers for using laptops or handheld devices were typically not the main focus. One exception is the study by Garthwait and Weller (2005) that sought to examine the factors that facilitate as well as hinder teachers in using laptops in a Maine classroom. However, there were limitations to Garthwait and Weller's study: convenient sampling of only two teachers, and study context limited to only science-math content areas. Future research should be conducted to examine in greater breath and depth the barriers and strategies for using laptops and handheld computing devices (e.g., Palm^{TM}) using a larger sample and in other subject content areas.

Types and quality of previous studies

Finally, we discuss the types and quality of past research studies that have been conducted on technology integration. Using the types of research study categorization frameworks of Ross and Morrison (1995), as well as Knupfer and McLellan (1996), the 48 studies may be categorized as follows: (a) 38 were descriptive studies[1], (b) three were correlational studies, (c) four were a mixture of descriptive and correlation studies, and (d) three were quasi-experiments.

The quality of past research studies on technology integration appeared to have one or more of the following four main limitations: (a) incomplete description of methodology, (b) reliance on self-reported data, (c) short-term in duration, and (d) focus primarily on the teacher and what went on in the classroom. First, regarding the incomplete description of methodology, 12 of 48 studies did not report the research duration. Reporting the duration is important because it informs the reader whether the study is short-term or long-term. We suggest that there are benefits to conducting longitudinal studies on technology integration. In addition, 7 of 48 studies did not report the number of participants involved, and 21 of 22 studies that used observations as a means to gather data did not report any interobserver or intraobserver agreement reliability. Knupfer and McLellan (1996) argued that because human observers may have biasing expectations, and their recording methods may change over time due to fatigue or practice, it is important that an assessment of both interobserver and intraobserver reliability be conducted for observational research.

A second concern is that half of the 48 studies based their findings solely on the participants' self-reported data such as interviews or surveys. Self-reported data may not give an accurate depiction of how technology is actually used because teachers' beliefs, intentions, or perceptions do not always translate into practice. Furthermore, as indicated by Hakkarainen et al. (2001), a general problem of studies based on self-reported data is that participants usually have correct notions about socially desirable answers, which can be referred to as the tendency to provide answers that cause the respondent to look good (Rosenfeld, Booth-Kewley, Edwards, & Thomas, 1996). Social desirability responding has long been viewed as a potential source of error variance in self-report measures (Hancock & Flowers, 2001).

[1] Descriptive studies describe conditions as they exist in a particular setting (e.g., the number of teachers at different grade levels who use computer-based instruction). It is primarily concerned with "what is" type of questions (Knupfer & McLellan, 1996, p. 1196). With descriptive studies, one may use qualitative data sources (field notes from observations, interviews), quantitative sources (descriptive statistics), or both (Ross & Morrison, 1995). Correlational studies examine how variables relate to one another (Ross & Morrison, 1995). A quasi-experimental study uses intact groups. It is similar to the experimental method, with the omission of the randomization component (Ross & Morrison, 1995).

Third, 25 studies were limited in their duration, ranging from as short as five days to less than two years. Short-term studies cannot fully address some issues that may be critical in helping us better understand technology integration. For example, a short-term study cannot examine the dynamic relationships between first- and second-order barriers over time. Neither can it determine the long-term effects of first- and second-order strategies, nor the stage theory of technology integration as advocated by its proponents. In addition, studies that are short-term may suffer from a "Hawthorne-type" effect, where teachers are more likely to demonstrate "model" technology-integrated lessons when observers visited briefly.

Finally, a majority of the studies (30 of 48) on technology integration in K-12 schools focused primarily on the teacher and what occurred in the classroom. Few studies included other potentially important variables at the school or district level that may be affecting the integration of technology by teachers. O'Dwyer et al. (2004) postulated that because technology-related decisions that can impact practices within the classroom are typically made outside of the classroom, it is important to examine potential technology-related policies that exist at the school and district levels.

What then should future research studies on technology integration look like? We suggest mixed methods research as the type of studies needed in the future. Mixed methods research is defined as "the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language in a single study" (Johnson & Onwuegbuzie, 2004, p. 17). Mixed methods research frequently results in superior research because of its key defining feature—methodological pluralism (Johnson & Onwuegbuzie, 2004). In addition, we suggest the mixed methods research that underpins future study on technology integration should be guided by the following principles. First, future mixed methods research studies should provide a rich, thick description of the methodology (including the length of the study, number of participants, interobserver and intraobserver agreement reliability) so that findings can be adequately interpreted. Second, future mixed methods studies should examine teachers in actual practice through observations, and not merely rely on self-reported data. Third, studies should be longitudinal in nature. Doing longitudinal studies not only provides researchers the opportunity to examine the dynamic relationships between first- and second-order barriers and strategies, or the stage levels of technology integration over time, but also to examine if the strategies used to overcome the barriers can impact students' learning outcomes in a positive way. Finally, future studies based on mixed methods research should expand the focus to include the examination of other stakeholders in the school such as the school administrators and leadership, as well as the broader contexts such as decision-makers outside the school. As Cuban (2001) reminded us, both groups—internal (i.e., school staff), and external (i.e., decision-makers outside the school) are necessary for technology integration in a school.

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