Information and Communication Technologies in Elementary and Secondary Education: A State of the Art Review

Charles S. Ungerleider and Tracey C. Burns
University of British Columbia

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Abstract

The literature devoted to technology and education is replete with claims regarding the contribution of computer technologies to teaching and learning in elementary and secondary schools. The claims have fuelled expectations and encouraged local and provincial school jurisdictions to expend significant resources on new technologies. This review of research is a response to the call by the Canadian Education Statistics Council to prepare a paper addressing some dimension of the impact of information and communication technology (ICT) on teaching and learning in elementary, secondary, or post secondary education in Canada.

We have focussed our review on two major areas: 1) the efficacy of ICTs for achievement, motivation, and metacognitive learning; and 2) the impact of ICTs on instruction in content areas in elementary and secondary schools. Mindful of the importance of contextual factors such as ethno-cultural and linguistic diversity, we have attempted to focus on Canadian research. Nevertheless, because the material devoted to Canada is scarce, we have augmented our review with international research on these topics.

It was our intention to identify claims that would enable those responsible for the formation or implementation of policy to make informed decisions. Few, if any, claims were sufficiently well researched or well evidenced to provide direction for policy. We conclude our review with a discussion of policy, the impact of research in the classroom, and suggestions of further research.

Introduction

Notwithstanding the significant attention and literature devoted to technology and education, there appears to be comparatively little empirically sound research upon which policy makers might base informed decisions. By empirically sound we mean research that addresses testable hypotheses using experimental or quasi-experimental methods, subjecting the data to appropriate statistical treatment, and drawing conclusions consistent with the purposes and methods employed.[1] What follows is a review of the literature devoted to technologies, especially the use of computers and computer related techniques, and their educational impact on student socialization and learning from kindergarten to grade 12. In the review we critique the literature in education, psychology, sociology, and technology; suggest its strengths and shortcomings; and identify areas where future work is required. Although our focus is on Canada, of necessity we included international research on these topics.

According to the most recent Pan-Canadian Education Indicators Program (PCEIP) report (Canadian Education Statistics Council, 2000), 88 per cent of elementary and 97 per cent of secondary school students attend a school that has Internet access for instructional purposes. With such widespread use of information and communication technologies (ICT), there is understandable interest in the impact of ICT on teaching and learning. Although it is often claimed that computer technologies and the Internet have the potential to change both teaching and learning, teachers have been subjected to public pressures to use new technologies before they, and we, have a clear understanding of their impact on classroom practices and student learning (Stuve, 1997). Schools and classrooms are being equipped without adequate research or attention to the professional preparation of teachers (Nicol et al. 1996; Ungerleider, 1997). Despite the PCEIP statistics reported above, the most recent Statistics Canada report (Tremblay et al., 2001) found that 70 per cent of teachers in Ontario schools reported that their students had either limited access or no access to a computer at school. This might be explained by any one of a number of reasons, including: a poor ratio of Internet connections to students, poor distribution of equipment, insufficient teacher preparation time, and structural impediments to the incorporation of new technologies in teaching (c.f. Cuban, et. al., 2001).

The belief that classrooms should be equipped with technology is predicated on the belief that technology can improve the rate, quality, amount, and effectiveness of learning (Henchey, 2001). Although attractive, this belief must be tested with sound research. As Abrami (2001) states: “To date, there is much promise but less substance, especially long-term evidence, regarding the effective use of technology for learning” (p.

[1] By design our approach eliminated consideration of material of a rhetorical nature without appropriate evidential support. Our focus also meant that we would not address work such as the Second Information Technology in Education Study conducted under the auspices of the International Association for the Evaluation of Educational Achievement with the participation of Canada (see, http://www.cmec.ca/stats/international/indexe.asp), SITES provides information about the use of information and communication technologies in Canada and other countries, and addresses such issues as barriers to the use of information and communication technologies in schools.

114). It is thus critical that the available research be assembled, reviewed, and critiqued as a prelude to pinpointing areas of future research and policy development. In this review we begin this process by focussing on two major areas: 1) the efficacy of ICTs for achievement, motivation, and metacognitive learning; and 2) the role of ICTs in instruction in content areas. Both of these foci relate directly to PCEIP indicators such as pupil-to-computer ratio, enrolment rates, completion rates, obstacles to fuller use of ICT, and innovation. We end our review with a discussion of policy and the impact of research in the classroom.

We initially sought to limit the scope of our review to peer-reviewed articles published during the past ten years. We searched a variety of sources for such material, including EBSCO Online, the Education Research Information Center (Eric), Sociological Abstracts, and PsychInfo databases. We also put out a call for Canadian citations on dpnet, a Developmental Psychology list server. In addition, a web search was conducted for policy reviews and the results of national and provincial testing related to our foci. Although not peer-reviewed, we felt that this information, particularly the data from national and provincial testing, was an important addition to this review.

1. Efficacy of ICTs for achievement, motivation, and metacognitive learning

Many studies show that preschoolers are “learning optimists” who rate their own abilities highly, underestimate task difficulty, and hold positive expectations of success. During middle childhood, children begin to distinguish ability, effort, and external factors in explaining their performance (Skinner, 1995). How they attribute success and failure on tasks influences the likelihood of developing an intrinsic motivation to persist at challenging tasks and the development of effective metacognitive skills. This in turn influences performance on academic tasks. In the following sections we will discuss each of these three aspects of learning.

1.1 Attitudes, attributions, and achievement orientation

1.1.1 Attitudes

Research (Allport, 1935; Oskamp, 1977) supports conventional wisdom indicating that students who are positively disposed toward tasks or subject matter are likely to learn more and learn more easily. For this reason, student attitudes toward computer use could have an impact on their learning.

Only one finding in the research on attitudes is clear: Children who are exposed to computers have a more positive attitude towards computers than those who are not (Clark, 1997; Dawes et al., 2000; Hennessy, 2000; Kirkman, 1993; Levine et al., 1998; Miyashita, 1994; Pedretti et al., 1998; Soyibo et al., 2000; Woodrow, 1994; although see Renaud, 1998). Positive attitudes towards technologies allow for their productive use throughout life.

Another finding is also relatively clear: Despite years of initiatives to engender positive attitudes among women toward ICTs and improve their efficacy in using them, men and boys still have a higher computer self-efficacy and more positive attitudes towards computers than girls and women (see Whitley's (1997) meta-analysis of over 80 studies; also Inkpen, 1997; Nelson et al., 1997; although cf. King, Bond, and Blandford, 2002). This discrepancy remains despite the reported *use* of computers in school rising to a non-gender differentiated level (Durndell and Thomson, 1997). It seems that simple exposure to computers does not guarantee positive attitudes towards them, or at least the positive attitudes are being mitigated in girls and women.

The gender discrepancy is being reduced, but much more slowly than predicted (Durndell et al., 1997). Gender differences have several implications. On a very basic level, it has been argued that the software most commonly used does not appeal to girls as much as boys, and should therefore be structured differently (Inkpen, 1997). On a social level, differences in attitudes have ramifications for school performance and achievement, especially in the context of group work. This topic will be discussed more fully in the section devoted to achievement below.

1.1.2 Attributions

Positive attributions of academic success fuel a sense of mastery and are part of a positive cycle of learning that is associated with academic success. In this cycle, successes are attributed to ability and internalized while failures are discounted and attributed to situational factors beyond the control of the learner (Dweck, 1978). In contrast, negative attributions of academic performance can give rise to learned helplessness, which is associated with poorer school performance. In this cycle, successes are discounted and attributed to luck while failures are internalized as indicators of low ability, leading to an overall sense of helplessness and failure. Students with learned helplessness perform less well on academic tasks than students who attribute their success to their own abilities. Attributions to ability versus luck are also related to gender differences, making the area an important one for research.

Despite the vast body of research on this topic in general, there is a paucity of work investigating how these cycles are manifested in relation to computer technologies. We could find only two studies on this topic. The first demonstrated that attributions to ability and task difficulty (Baron et al., 1996) had a more significant effect on performance than attributions to luck and effort on computer tasks. The second study investigated the effect of gender on children's reactions to success and failure on computerized tasks (Nelson and Cooper, 1997). It found that boys were more likely to attribute failure on the tasks to unstable and external causes (e.g., lack of effort, a bad disk) than were girls. In contrast, girls were more likely to attribute success on the tasks to unstable and external causes (e.g., effort, easy program).

1.1.3 Achievement orientation

There have been a number of recent large national analyses investigating whether access to a computer or use of a computer in instruction improves academic achievement. Tremblay, Ross, and Berthelot (2001) report an analysis conducted by Statistics Canada using data from Ontario's Education Quality and Accountability Office's province-wide tests. These data were gathered in 1997 from 115 000 third graders in Ontario's English-speaking schools. While other factors such as smaller class sizes were found to be related to higher academic achievement, this study found no relationship between the presence of a computer in the classroom and the achievement of third grade students (Tremblay et al., 2001).

In the United States, similar work has been done looking at the results of National Assessment of Education Progress (NAEP) tests. These tests, administered nationally every two years in mathematics and reading alternately, assess the effect of a number of variables, including computer use, on academic achievement. The most recent analysis available (Johnson, 2000) used the scores on the reading test for students in grades four and eight. The analysis revealed that students who used computers in the classroom at least once each week do not perform better on the NAEP reading test than do those who use computers less than once a week (Johnson, 2000). This was true even accounting for the comfort and training with computers that teachers reported: The analysis was restricted to teachers who reported that they were moderately well prepared to use computers for instructional purposes.

The most recent analysis of the data from the NAEP mathematics tests is reported by Wenglinsky (1998). Analysing the results of 6227 fourth graders and 7146 eighth graders, he found that the frequency of school computer use and achievement were inversely related; student with greater school computer use performed less well than students with less school computer use. For eighth graders, he also found that the use of computers to teach lower level cognitive skills (e.g., drill and practice mathematics programs) was negatively related to academic achievement. However, the use of computers to teach higher-level cognitive skills (e.g., simulations and applications) was positively related to academic achievement. Unfortunately, eighth graders from disadvantaged groups were significantly more likely to be taught lower level skills than higher-level ones. On a positive note, fourth graders who used computers for learning games had higher levels of academic achievement than those who did not. Overall, he found that the size of the relationships between technology use and academic achievement was large for eighth graders but not for fourth graders. Gaps in achievement may be expressed as a relationship between the relative position of learners vis a vis their peers. Based on a 36-week instructional period, Wenglinsky found that fourth graders using learning games were approximately 3 weeks ahead of their classmates. In contrast, eighth graders who are exposed primarily to drill and practice programs on the computer are just over 21 weeks behind their classmates.

Canadian and American data indicate that academic achievement does not improve simply as a result of having access to computers in the classroom. These kinds of investigative studies are important, given the large sample size, diverse geographical and instructional settings, and level of detail in the data collection. However, these are not experimental investigations in that the presence or absence of computers was not purposely manipulated. In order to make causal arguments regarding the effects of computers on academic achievement, well-conducted and analysed experimental work needs to be conducted.

Much of the current research suffers from methodological or theoretical constraints that limit the applicability of the results. The most common methodological flaws are the lack of a control group, nonrandomized designs, raters that are not blind to the experimental manipulation, and/or interpretations that are unwarranted by the data. An example of one study that suffers from some of these limitations is the work of Ainsa (1989), who investigated the effects of adding computers to Head Start curricula for 4 and 5 year olds. She found that the addition of computers yielded higher achievement in all content areas (motor, cognitive, and language) than the achievement of a control group, and concludes that the use of computers in the Head Start curricula improves performance. Although the result is superficially plausible, it masks a likely underlying cause of poor achievement: The students who were performing poorly were being taught by teachers-in-training who were not as effective as experienced teachers might have been. When the children were taught by experienced teachers (as opposed to teachers in training), she found that performance improved in all areas to levels comparable to the computer conditions. Overall, she found no effect of computers on academic achievement, except in the case of less qualified instruction. This is not to say that this is an unimportant result. Clearly, if students are being exposed to less qualified instruction, it is constructive to note that the addition of computerized tasks designed by capable instructors has a positive effect on academic achievement. But it is misleading to portray the role of computers so positively while downplaying the importance of quality instruction. Similar results regarding the crucial role of an effective instructor have been reported by Knapp (1997), and Tremblay et al. (2001).

Experimental results regarding access to computers without additional instruction are provided by Gardner et al. (1993), who supplied 235 students with a personal laptop for an entire school year and matched them to a control group that did not receive computers. Instruction was the same for both groups. After the year, performance in English, mathematics, and science was measured. No significant differences were found between the two groups, suggesting that mere access to computer technologies without concurrent changes to instruction is not sufficient to affect achievement.

There are many examples of innovative programs combining access to technology with instruction designed to complement the new technological resources. Woodrow and colleagues (Pedretti et al. (1998); Woodrow et al. (2001)) have longitudinal evidence of the effectiveness of technology-enhanced instruction in a secondary science environment. In particular, they report on the experiences of high school students in a multimedia environment in Physics and Science classrooms. They have a substantial amount of data collected through interviews and questionnaires that indicate that the students enjoy working in the multimedia environment and believe that they are learning specific knowledge and general learning skills in a way that would not be supported by traditional instruction. Their series of papers, although insightful and interesting for the qualitative data presented, suffers from two major shortcomings: the lack of a control group and a non-random selection of the students interviewed. All of the interviews were conducted with a subset of students who were in the experimental classroom, preventing a comparison with students in traditional classes. It may very well be that the kinds of comments the multimedia group made were unique and a result of their novel learning environment, but, as there was no control group with which to compare them, this cannot be confirmed. These shortcomings seriously limit the power of their argument.

There are some indicators of a positive effect of computers on academic achievement: Positive relations between computer use and achievement as a function of exposure to computer assisted instruction have been reported by Renaud (1998), who looked at science performance of seventh grade low achievers. Similarly, van Daal et al. (2000) reported dramatic increases in reading and spelling performance of kindergarten students who were exposed to a computer-based reading and spelling program over those not exposed to a computerized program. In addition, one very well controlled study found a clear, positive relationship between the use of hypermedia instruction and achievement in engineering courses (Zywno et al., 2001). There is thus some empirical support for a positive effect of technologies on student performance. However, it is difficult to interpret these findings in light of the null or negative effects reported in the

Canadian and American studies using large-scale student assessments to which reference was made earlier in this paper. More carefully conceived and executed experimental research is clearly needed before conclusions can be drawn.

1.2 Motivation

There has been a long-standing argument that the use of computers for instructional purposes increases motivation in children (Trentin, 1996). Laferrière et al. (1999) point out that children without access to a computer at home will find it more motivating to go to classes where they have the opportunity to use a computer. Although intuitively reasonable, they offer no experimental support for this statement. Findings that do offer empirical support include those of Howland et al. (1997), who demonstrate that children using computers (in this case, the program KidSim) were highly motivated to complete their assignments and demonstrated high levels of curiosity, achievement orientation, and personal ownership of the project. Barak et al. (2000) argue that the use of technology in Israeli classrooms in high school increases pupils' self-efficacy and motivation to study and succeed. Olsen-Rando (1994) reports that these motivational effects are also extendable to therapeutic settings. Similar results have been found with eighth and ninth grade science students (Hennessy, 2000). Unfortunately, none of these projects had a control group of students that did not use computers. One study that did have a control group (Dawes et al., 2000) showed no significant effects of computer work in task achievement of seventh and eighth graders, but the students did report valuing the computerized task more than the non-computerized control task. Other work refutes this argument, however. Kinzie et al. (1992) demonstrated that, in a Grade 9 science class, increased motivation as a result of computerized tasks was divided on gender lines. Boys showed increased motivation, but only when they were in a condition where the program controlled the information presented. When the boys controlled the learning and information, there was no effect on motivation. Girls showed no significant effects of computer use on motivation regardless of their condition. Similarly, Miyashita (1994) found no effect of computer use on motivation in a study of Japanese 1st and 2nd graders.

These findings indicate that group work with the use of a computer does not by itself increase learning or satisfaction, but rather aspects of social facilitation and the collaboration process underlie many of these results. Svensson (2000) has reported that third grade pupils working in groups on computer tasks have higher levels of interaction and, unlike other tasks, most of these interactions were concerned with solving the problem. When asked, children in her study reported that the limited time they had on the computer required them to focus on the task at hand, thus concentrating their efforts and encouraging on-task interactions. Orth et al. (1994) report similar findings with temperamentally challenged kindergarten students. In an intriguing reversal, Ocker et al. (1999) studied performance on face-to-face tasks without a computer versus a computerized conferencing technology that required asynchronous group work. They found no significant effects of either manipulation on quality of work or learning, but did find a significant reduction in satisfaction with the task in the computerized conferencing technology requiring asynchronous group work

1.2.1 Usability and human factors:

Children are not adults- their motor skills, cognitive abilities, and motivations are different. We must take into account children's abilities in all these realms in order to develop appropriate technologies and learning programs. This includes the design of the computer systems (both hardware and software) and the learning environment itself.

There are few studies on how computer systems and learning environments are designed, constructed, and maintained. Stuve (1997) reports on a three year descriptive case study (dual level third and fourth grade students) in which he explored the role of technology in the classroom after it had been installed, that is, how it was used by both the teachers and the children over several years. He found that specific features of the classroom environment, for example the location of the printer in relation to the class and the quality of the computers, had important impacts on how projects were structured and how learning activities were maintained. He argues that the realisation of technological innovation is socially constructed, with a complex interaction among students, teachers, and the physical and social environments supporting the technologies. This is the only study we could find that investigated this issue. Although it is a well-documented study, its descriptive nature does not permit hypothesis testing. It is imperative that more rigorous experimental research be done on this area.

The design of the learning environment also includes the ratio of computers-to-students, affecting the size of learning groups that can be formed (see Bracewell et al., 1998). According to the most recent PCEIP indicators, there was one computer to every nine elementary students, one to every eight lower secondary students, and one to every seven upper secondary students. Several investigators (Alspaugh, 1999; Baron, 1992) have examined the impact of computers in working groups of five or fewer students. The availability of computers does not appear to be a factor in educational outcomes under such conditions.

The nature of hardware and software affects both its use by and its impact on the learner. In an empirically sound program of study Inkpen (1997) argues that the design of hardware and software must take into account both motor and cognitive skill differences between children and adults. As part of this, she focuses her work on certain aspects of low-level interface design. Inkpen (1997) found that low-level design details such as number of mouses and type of mouse had significant effects on children's performance and motivation. Based on children's preference, speed, and number of errors, she found that children found the drag and drop operation style of a mouse to be more difficult than a point and click operation. Joiner et al. (1998) have also reported similar results. Inkpen (1999) reports preliminary data on children's preferences for computer design and interface in a program of research aimed at designing computing environments for handheld systems. Inkpen's research is illustrative of the promise and potential importance of human factors research devoted to information and communication technologies in education.

There is as yet very little comprehensive or rigorous research investigating the software design and the effects of design features on student learning and performance.

Lauret (1999), argues that although the role of visual presentation in information processing is well understood, increasingly sophisticated auditory presentations require further investigation. His preliminary findings suggest a role for both auditorally and visually complex programs and interactions. In similarly promising work Benshoof et al. (1995) demonstrate that the use of multiple windows in complex tasks helps fourth grade students complete their work better than the use of single window presentations. Passig and Levin (1999) demonstrate that gender plays a significant part in the effectiveness of the design interface for kindergarten children. They found that boys preferred the use of navigational buttons when searching for assistance whereas girls preferred to ask for help. In addition, girls preferred scenes that changed slowly, incorporated text into the game, and were colourful with an emphasis on reds and yellows. Boys preferred scenes that changed quickly and emphasised blues and greens.

The software programs used in schools receive very poor evaluations, despite a clear understanding that instructional materials are more effective if their development has been informed by research. Coley et al. (1997) offer an overview of the results obtained by the California Instructional Technology Clearinghouse (CITC), which is a state funded organisation that conducts evaluations of software based on research and educational standards. Based on the recommendation of the US Department of Education's Office of Educational Technology, most commercially developed software is submitted to the CITC. Between 1991-1995, the CITC rated less than half of the courseware submitted as having enough quality to merit further evaluation. Of those evaluated, only six to eight per cent were rated as "exemplary", and from 33 to 47 per cent as "desirable" (Coley et al., 1997, p.52). The results of the CITC evaluation and the paucity of research in other areas of usability/human factors illustrate the need for careful development of all aspects of computer technologies before they are installed in the classroom, and point to an area that requires further research. In addition, we must not forget that the most carefully designed systems are only effective when they are integrated into instructional practices and used as designed (Benton Foundation Report, 1997).

1.3 Metacognitive skills:

Metacognitive knowledge includes knowledge about the self, the task, and strategies for learning. Memory and general problem solving skills also play a role in the effective use of metacognitive resources. The development and implementation of successful metacognitive skills can significantly influence learning and scholastic performance.

1.3.1. Learning strategies:

Group work is seen as one of the major places where computer use can add to traditional instructional practices. The participation that is required when children are grouped around a computer, as opposed to working in isolation at individual computers, can have a positive effect on performance (Inkpen, 1997; Lou et al., under review). Eraut (1995) demonstrates the effect of social interaction and group work in British primary schools, arguing that the use of a limited number of computers in a class setting encourages collaboration, decision making, turn taking, participation, argument, and conflict. Mevarech et al. (1992) argue that peer based interaction at the computer allows for exploration of the relationships between cognitive, metacognitive, and social processes. In particular, co-operative learning on computers is argued to facilitate peer interaction and have implications for motivation, self-esteem, and social behaviours.

The extent of group effectiveness, at least in the 9-12 age group, is determined by several crucial factors, including the degree of autonomy developed by students, type of negotiation within a group, and the extent to which pupils appropriate the task (Hoyles et al., 1992). This argument is supported by Kinzie (1992), who reports a positive effect of autonomous learning on performance. However, the benefit of greater autonomy (that is, increasing the control the child has over the learning process) can vary. The task assigned has been shown to dictate whether more or less autonomy is desirable. For ninth graders in a physics classroom, too much autonomy diminishes learning about the data themselves (Clark, 1997). Similarly, Gillingham et al. (1989) found that high levels of autonomy on difficult synthesis tasks (reading) were detrimental to the performance of the fifth graders they studied; even though more structured help was available through the computer program, the children chose not to use it to the detriment of their learning. Similar results regarding the need for structure in Internet searches in young children are reported by Reed et al. (1997) and Schacter et al. (1998). These researchers caution that student choice as to whether or not to use available structure can, at this age, result in diminished performance. Younger students, such as the five and six year olds studied by Klein et al. (2000), perform better when there are adults mediating the learning and providing structure. With older students, however, greater autonomy can be positive: Adnanes and Ronning (1998) found that secondary students took more responsibility and worked more independently when given greater autonomy.

All groups are not created equal. In terms of the benefits of computer use, *who* is doing the work seems to be just as important as *what* work is assigned. Hoyles et al. (1992) argue that the importance of the pupil-teacher interaction is crucial in determining the composition of groups to include the diverse personality and work types that encourage the best group performance. One aspect of who is doing the work is gender. Joiner et al. (1998) found that performance in group work tasks differed as a function of gender and level of expectation. Ten and 11 year olds were randomly assigned to low and high expectation groups in which the expectation of performance was manipulated by level of difficulty of a pre-test. Students given a difficult pre-test had lower expectations of success on the task than those given a simple pre-test. Students were further divided into an individual condition and a social comparison condition in which they worked on the task either individually or in groups. The presence of similar others, defined as those who had the same expectation, facilitated the performance of girls who had high expectations of success, but had the reverse effect for girls with low expectations of success. The presence of others had no effect on the performance of boys. These results have importance for educational settings in that group work is often encouraged, yet it does not appear to be uniformly positive for all children. In particular, for children with low expectations of success, the presence of other children who have similarly low expectations has a negative effect. Girls are disproportionately more likely to have low expectations of success (Whitley, 1997, Inkpen, 1997), and as a result might be particularly vulnerable to negative aspects of group work.

The importance of the composition of groups is contested by other studies. Kutnick (1997) has found that training children in social skills is a better determinant of computer-based problem solving abilities than either gender or group composition. Yet Baron (1997), in a similar intervention with fifth and sixth grade students, found no effect of training in group social dynamics or in grouping according to ability. Baron et. al. (1992; 1996) have also demonstrated that group size (one vs. two or four) did not have an effect on fifth and sixth grade performance. Similar findings have been obtained by Alspaugh (1999), although Littleton et al. (1992) found that performance of pairs was better than that of individuals in a game format.

Further complicating the argument, Amigues et al. (1993) suggest that it is the kind of problem that students face which determines whether or not a group effort will be more successful than an individual one, regardless of computer use. They investigated the performance of individuals or dyads in their attempts to solve physics problems. Participants were presented with either a canonical version of a physics situation (i.e., one that used rules currently employed in class) or a noncanonical version (i.e., the rules were not used in class). With canonical situations, there was no difference in performance between the individuals or the dyads. In noncanonical situations, however, the dyads performed better than the individuals. This argument is supported by the work of Healy et al. (1995), who demonstrate that performance on conceptually based mathematics projects was aided by group work, whereas performance on mathematics projects that required the use of technology benefited more from individual work. All of these results are further qualified by the findings of Treacy (1996), who argues that learning styles (environmental, emotional, sociological, and computer) interact with beliefs about technology, gender, and grade level to effect performance.

1.3.2 Memory tasks

Memory strategies such as rehearsal become more effective over time and lead to better retention of information. One of the major technological attempts to encourage the use of rehearsal strategies in learning, and thus better retention of information, has been the use of computer-assisted instruction (CAI). As discussed in the achievement section above and in the subsequent sections, there has been a vast literature on the use of CAIs in a variety of subject areas. Despite the large number of published articles on the topic, there is still not a clear indication of whether or not CAIs are effective at enhancing performance (see Coley, 1997; and Wenglinsky, 1998, for contrasting claims).

1.3.3 Problem solving

There is a general argument that using computers makes pupils better problem solvers and autonomous learners by encouraging the development of independent thinking skills beginning as young as preschool (Scherer, 1989). This broad claim has been partially supported. Wheeler et al. (1999) exposed ninth graders enrolled in algebra classes with traditional instruction to one of three conditions: 1) a control group; 2) a placebo condition, where students were given a computerized word problem environment without active tutoring; and 3) an experimental group that received a computerized word problem environment with active tutoring. They found that the students who received the computerized tutoring system performed better on both abstract and concrete reasoning word problem tasks than age mates in the other two conditions. However, they did not do better than students given human tutoring as a supplement to traditional instruction. In addition, although the tutoring system was designed to increase the ability to solve problems of a more abstract and theoretical nature, the students actually showed more improvement on the concrete test questions than the abstract ones. This study is an example of a relatively strong research design: Nicely balanced (students all had the same amount of overall instruction, regardless of condition), a large sample size, and a control condition. Because students were not assigned to conditions randomly, it is plausible that the results are attributable to the pre-existing differences between the control and experimental groups, as the experimental group scored significantly higher on test problems even before the manipulation. Notwithstanding its limitations, the study provides limited support for the argument that the use of computer tutorial programs has the potential to help students with problem solving skills.

Other research offers little or limited support. Margoulis (1988) demonstrated that games can be used to stimulate learning and especially problem solving, but again this study is limited by the absence of a control group. Hasselbring et al. (1996) argue that computerized mathematical environments help first to third grade students with problem solving in mathematics. However the benefits observed in the experimental group were also observed in the control group. Because the groups were vastly different in size, the experimenters avoid a direct comparison of the two groups, although, of course, this is a necessary step for coherent conclusions. Other studies have similar limitations (e.g., Somekh, 1991).

2. The role of ICTs in instruction of particular content areas

Instructional strategies vary in relation to the nature of the content and in relation to characteristics of the learner. For this reason, we sought material that might shed light on the impact of information and communication technologies in specific content areas.

2. 1. Writing, reading, and spelling

2.1.1 Reading and spelling: A recent Canadian study (Chambers et al., 2001) proposes the use of a program called the Reading CAT for children with reading problems. Their initial study reports favourable ratings given to the technology by both the children and the tutors, but, as yet, they do not have any quantitative data on achievement or improvement due to the use of Reading CAT. van Daal et al. (2000) have demonstrated that kindergarten children given a reading and spelling program dramatically improved their performance relative to peers not given access to the same program. In addition, for low achievers, the use of the computer program increased interest and decreased non-task directed behaviour. Similar positive results in the realm of reading and spelling are reported in a case study done by Nixon-Ponder (1999). In her study of two children, performance did not improve but enjoyment and motivation did, thus allowing for more enjoyable and focussed time at school.

2.1.2 Writing: Becker (2000) conducted a national survey of teachers and found that teachers report improvements in children's writing as a result of the use of a computerized program. He does not have data from children's performance, however. Rosenbluth et al. (1992) demonstrated that use of computer-based instruction for writing did not improve overall essay writing quality for eleventh grade students, although writing fluency improved. The improvement was greater for accelerated students than remedial students. Similar results with grade four and five students of average ability were also reported (Moore-Hart, 1995). Wideman and Owston (1997) demonstrate that student participants in Writers in Electronic Residence, a Canadian program that links authors to classrooms, are judged by their teachers to write with an improved sense of audience and maturity. However, this study did not use a control group, nor did it have blind raters: the same teachers who are aware of students' participation in the program provided the assessments. Owston's (1997) study is better designed: He compared the writing performance of a group of students with high computer access to a group with low computer access over a three year period. At the end of the three year period, children in the high access group did better on all measures of writing ability, wrote more, and were more likely to actively edit their compositions than children in the low access condition. A meta-analysis reports similar findings (Bangert-Drowns, 1993). In contrast, Evans (1991) found that writing performance in a Grade 8 classroom was not affected by the use of a specialised writing program. Nonetheless, the children believed that they were doing better, and thus reported better attitudes to the task. Of the 242 software programs under the banner of English/language arts submitted to the CITC for review, only 38 per cent were judged of sufficient quality to merit an evaluation. Of those, 21 per cent were rated as "exemplary" and 79 per cent were rated as "desirable" (Coley et al., 1997).

2.2 Art: Wohlwill et al. (1988) argue that elementary students require more and more cognitive control over their artistic creativity as they develop, and thus programs should be devised that allow them this control while at the same time encouraging their artistic expression.

2.3 History/social studies: Of the 208 programs submitted to the CITC for review, only 33 per cent were judged of sufficient quality to merit an evaluation. Of those, 26 per cent were rated as "exemplary" and 74 per cent were rated as "desirable" (Coley et al., 1997).

2.4 Mathematics: The largest volume of research on the impact of technology in the content areas has been conducted on mathematics instruction. Mathematics instruction also has the longest history of using technology for instructional purposes and boasts several impressive systems and programs for the instruction of mathematics and mathematical concepts. Of the 135 programs submitted to the CITC for review, only 21 per cent were judged of sufficient quality to merit an evaluation. Of those, 21 per cent were rated as "exemplary" and 82 per cent were rated as "desirable" (Coley et al., 1997).

Software for mathematics can be divided into two sections: drill and practice programs, and higher-level conceptual programs.

2.4.1 Drill and practice programs: In use since the 1960s and known as Computer Assisted Instruction (CAI), there have been numerous studies of CAIs.[2] In review papers and meta-analyses, Christmann et al. (1997), Kulik and Kulik (1991), and Liao (1992) find significant and generally positive effects of CAIs on academic achievement, but caution that the size and direction of the effects vary according to the methodology used. A similar argument is made by Coley (1997). In contrast, Wenglinsky (1998) argues that the use of drill and practice programs has a negative effect on achievement. He also claims that CAIs are not cost effective: tutoring produces greater gains for less money.

2.4.2 Higher-level conceptual programs: Wenglinsky (1998) finds that teaching higher-level mathematics concepts to eighth graders (e.g., applications and simulations) has a positive effect on academic achievement. Borton (1989) reports that individualized computer managed instruction significantly increased the performance of 5th graders. However, even in this subject the research is not unanimous. Seagraves (1998) studied 12-17 year olds and found that, for children and adolescents at risk, the use of computer technology was not better than the use of a qualified and caring teacher.

2.5 Biology: Soyibo et al. (2000) have argued that the use of computer-assisted instruction (CAI) significantly improves performance in a high school biology class as well as improves attitudes towards computers. However, this study is poorly designed. Participants in the experimental group attended lectures, discussions, and engaged in CAI in biological concepts. Because participants in the control group attended only the lectures and discussions, thus spending less overall time in biology instruction, it was impossible to discern whether the improved scores obtained by the experimental group were due to CAI, as the authors suggest, or merely a result of increased exposure to the topics.

2.6 Physics: Clark (1997) argues that many aspects of physics lend themselves to computer displays and learning programs, and has demonstrated that students enrolled in a ninth grade class that employed computer technology benefited from its use. Although they did not outperform the control groups, their attitudes were more positive and they were more motivated to continue with tasks and labs than students in classes without such technology. He does, however, criticize many computer-based lab techniques as too unstructured and requiring too much of the student. He recommends that the programs be structured such that the cognitive demands of using them are reduced and students can concentrate on the labs, instead of the technology. Pedretti et al. (1998) argue that the use of multimedia technologies in the classroom encourages student enrolment and increases enjoyment of the class. In particular, their ninth to twelfth grade students reported appreciating the self-pacing, flexibility, and ability to work with peers. Similar results have been reported by Coley (1997) and Winne et al. (1998). Although

[2] Although we believe that the use and effects of computer assisted instruction with students who have special educational needs merits examination, it was beyond the scope of this review to undertake such an examination.

interesting, the Pedretti study suffers from serious limitations (lack of control group and non-random assignment to groups).

2.7 General science: Hennessy (2000) reports that the use of computer technology and graphing instruments in a weather project increased student motivation, enjoyment, and understanding of graphing techniques. Pedretti et al. (1998) have similar data with general science students, as do Kinzie et al. (1992). Yalcinalp et al. (1995) found that use of computer technology to teach chemistry in Grade 8 resulted in better performance and better attitudes towards chemistry than the use of standard instructional recitation hours. Bruce et al. (1997) provide similar evidence, but it is only descriptive in nature. Of the 295 programs submitted to the CITC for review, only 47 per cent were judged of sufficient quality to merit an evaluation. Of those, 20 per cent were rated as "exemplary" and 80 per cent were rated as "desirable" (Coley et al., 1997).

2.8 Geography: Koetter (1990) found through systematic evaluation that, although the use of computers to teach geography concepts was feasible, the 5th graders studied responded most positively (and performed best) with live instruction. In contrast, Yusuf (1994) found that 7th and 8th graders had a significantly deeper understanding of fundamental geography concepts with computerized instruction than a control group.

2.9 Other: There are a number of other subject areas that have been using computer technologies for instructional purposes. Innovations in the production of desktop educational materials include involving students as multimedia designers (Liu, 1998), designers of data bases (Scardamalia and Bereiter, 1996), motion picture authors (Baecker et al., 1999), or as project collaborators (Ward et al., 1997). Positive results are reported in all cases, with students demonstrating enhanced motivation, enjoyment, and performance. Chewning et al., (1999) report on the use of a computer based contraceptive decision aid for females in late adolescence. Their large sample showed significant and long lasting effects on knowledge and decision making confidence as a function of exposure to the computerized program.

3. Conclusions

Based on our review there is support for only four unambiguous claims:

- Student attitudes toward computers and computer related technologies improve as a consequence of exposure to them.
- The use of ICTs for group work can be beneficial if teachers are able to take into account the complex interplay among the age of the students, the kind of task, and the amount of independence allowed.
- The use of ICTs for mathematics instruction has a significantly positive effect on teaching high level concepts to students in grade eight or above.
- The majority of the research reviewed is contradictory and/or seriously flawed.

4. Implications of research for the classroom

The lack of empirically sound work and the absence of unequivocal results thwarted our intention to identify more fully practices that might profitably guide instruction. The preliminary research on usability of software and systems and professional assessments of instructional programs reported by Coley et al. (1997) should give any educator pause about adopting software without carefully considering its applicability to the intended instructional goals. An aspect of the educational setting that should not be overlooked is the age of the students, as the effect of computers on different age groups can be radically different. For example, the same ICTs that have no effect on one age group might have a substantial effect on another age group (e.g., drill and practice mathematics programs had no effect on fourth graders but significantly negative effects on eighth graders (see Holden, 1998, for a commentary)). Based on our review, almost all of the topics addressed require further investigation. In particular, we think that the following deserve further scrutiny in carefully conceived and executed studies.

- How are attributions to ICT task performance affected by gender?
- Achievement motivation and scholastic performance: How do we reconcile findings from large-scale assessments showing no or negative effects of access to computers with contrasting experimental results? One aspect of this question, which appears to be critically important and which we were unable to address because of resource limitations is the role of the instructor and instructor preparedness.
- What is the impact of ICTs on student motivation, and how do we measure it? Is it sufficient to have self-reports of increased motivation, regardless of the student's performance, or should there be more objective measurement?

- How are ICT environments designed, including the hardware and software? Results in this fledgling area of research reveal important effects on performance due to these often overlooked factors. Are we designing our systems so that they take into account the motor and cognitive development of students at various ages?

- Are metacognitive skills being enhanced by ICT learning environments? Is there a role for drill and practice programs in any subject area? Do general problem solving skills develop as a result of aspects of ICT work? Research on these topics is contradictory. The results often depend on the methodology used. Even a topic as seemingly simple as learning strategies engendered by group work generates conflicting results. Is the complexity of research findings on this topic being incorporated into programs and instructional design?

- What is the role of ICTs in particular subject areas other than mathematics or language arts?

5. Implications of research for the development of policy

Much of the research reviewed above has been conducted outside of Canada. Although such information is useful, it does not provide a uniquely pan-Canadian perspective. Unfortunately, the number of Canadian quantitative studies that have been published in peer-reviewed journals in the last decade is small. Those that are published often suffer from the same methodological and theoretical constraints that limit the utility of most studies of ICT in educational contexts.

The Canadian context for education is unique. A tradition respecting the preservation of distinctive linguistic, cultural, and ethnic differences, close proximity to the United States, and a federal government reluctant to intrude in an area of provincial jurisdiction are unique conditions that should be taken into account in studies involving education. Linguistic diversity alone poses a challenge to the production and use of educational software in Canada's three main population centres. Significant numbers of students for whom English or French are not first languages pose a challenge to the use of any instructional approach, including ICTs. Distinctive cultural and gender differences - such as working independently versus working in a group - pose additional challenges to devising appropriate instructional strategies for using ICTs in the classroom.

We were thwarted in our desire to identify research that would inform policy decisions concerning the use and implementation of ICTs in elementary and secondary schools. There are simply too few studies of sufficiently rigorous design to permit informed policy choices. This is especially troubling given that the use of ICTs requires significant expenditure of scarce resources. A long-term goal in this or any area is to have beneficial policy alternatives to which one can attach costs. This approach is too infrequently used in education, a situation to which the paucity of clear policy alternatives involving ICTs contributes nothing.

Simply put, we don't know enough about the impact of the use of ICTs in elementary or secondary schooling, and what we do know is sufficiently complex that there should be serious effort to support systematic, programmatic research capable of providing policy alternatives to which costs can be attached. For every dimension - from the accessibility of computers to the design of the software and hardware to the accomplishment of students and the social orientations that result - we see the need for clear, thoughtful, and programmatic research. After reviewing more than 800 research articles, Jones et al. (1998) argue that, given the complexity of learning outcomes as they relate to technology, there is a dire need for research projects of a sufficiently complex and formal level to support decisions by technology adaptors.

Results such as those obtained by Wenglinsky (1998) point to the need for rigorous research about the impact of ICTs on teaching and learning. Because the time for instruction is limited and, once lost, cannot be recovered for a particular subject without reducing the time for instruction in other subjects, policy makers as well as teachers have an obligation to enhance the positive uses of the technology and to eliminate the deleterious consequences. Determining what is positive and what is harmful is an essential first step in the process.

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