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ABSTRACT

The basic premise for this paper is that any educational program or technology should be evaluated on the basis of the theoretical foundations or perspectives on which it is implicitly or explicitly based. Structured in three main sections, it reviews recent literature in areas related to the many aspects that influence learning through telecommunications and computer conferencing. The first section is an overview of how cognitive theory can provide a basis for understanding computer-mediated communication (CMC) activities, with respect both to their educational potential and to the interaction of the learner with a computer system, and how the individual interacts with information on the basis of previously acquired knowledge and mental models. The second section reviews the literature that relates technologies such as CMC to their impact on education and society, providing a basis for thinking of new roles for teachers and learners, and helping to identify some of the prospects that students will face as they reach the workplace. The third section describes research theories and methods that have been used in similar contexts and could be useful in determining ways to evaluate the impact of telecommunications technology on student learning in the context of the teaching and learning environment. Over 100 citations and 56 other readings are included. (ALF)

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Information, Telecommunications and Learning: A Review of the Research Literature

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Research and Evaluation

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Executive Summary

The basic premise for this paper is that any educational program or technology should be evaluated on the basis of the theoretical foundations or perspectives on which it is implicitly or explicitly based. Phase I of B.C.'s SITP had a fairly general rationale: the desire to link districts and students to each other and to various sources of information, including legal experts, writing mentors and information databases.

For Phase II, formulating a more in-depth and specific rationale would assist in identifying research topics and methods of evaluation that would focus on the impact of telecommunications technology on student learning in the context of the teaching and learning environment.

This paper reviews recent literature in areas related to the many aspects that influence learning through telecommunications and computer conferencing, and is structured in three main sections.

The first section is an overview of how cognitive theory can provide a basis for understanding computer-mediated communication (CMC) activities, with respect both to their educational potential and to the interaction of the learner with a computer system. There is a large body of literature relating to these topics, all of it related to attempts to understand how the individual interacts with information on the basis of previously acquired knowledge and/or mental models.

The second section reviews the literature that relates technologies such as CMC to their impact on education and society. This provides a basis for thinking of new roles for teachers and learners and can also help us identify some of the prospects that students will face as they reach the workplace.

The third section describes research theories and methods that have been used in similar contexts and which might assist us in finding ways to evaluate the current project.

Introduction

It is difficult to evaluate the effectiveness of any new educational program or technology in the absence of a theory or rationale behind its initial implementation. For instance, Pea and Soloway, in a report for the U.S. Congress Office of Technology Assessment (1987), describe the importance of research in the cognitive, social, and instructional sciences, and the accompanying use of theory-guided educational technologies, as a tool to help bridge the "ever-widening gaps between schools and society" (pp. 33-34). Placing their research agenda in the context of an educational system which is intended to relate to the needs of society, provides them with a set of criteria for the evaluation of that research. In the same report, these authors also state that theories of technology in education can develop responsively to the feedback provided by applications in real settings (p. 47).

The literature reviewed in this paper is organized to assist the reader in identifying current thinking about some of the main issues that have impact on the research agenda for Phase II of SITP. Research in cognition can provide a basis for understanding strategies of learning, both as a background for the creation of educationally relevant telecommunication activities and with respect to the system itself and the user interface. Research relating to cultural (including school culture) and other changes that accompany the expanding access to information and associated technologies can help us address the new roles of teachers and learners, and can also help us understand the place of technology in the society of the future. Finally, an overview of the research methods and results from other technology-based projects (both within and outside of educational environments) can assist us in finding methods to evaluate our current project.

The Cognitive Perspective

To an increasing degree over the past two or three decades, cognitive science has provided a perspective for understanding the interaction of an individual's mental functioning and the complex contexts in which it occurs. This perspective has influenced fields such as psychology, economics, ergonomics, linguistics, artificial intelligence, information sciences, and – of particular importance to this literature review – education.

What does cognitive science tell us about learning?

The attempt to define learning is frequently omitted from discussions (whether verbal or written) about learning and effective learning environments. At this point, it might be sufficient to say that the implied (or sometimes actually stated) definition of learning in most of the literature reviewed here includes the notion of cognitive change.

Some main points from the cognitive perspective are as follows:

- learning involves the active construction of mental models
- the learner's world view (existing models or structures, including strategies for categorizing and integrating information and concepts) mediates the processing of new information
- learning can never be completely detached from context.

The cognitive view of learning accommodates what we intuitively know about human diversity and adaptability. Chesebro & Bonsall (1989) have described this in the following way: "Human beings react to many different kinds of information, develop different conceptual systems to deal with them, and ultimately generate multiple ways of perceiving and understanding any single event or phenomenon" (p. 39). Active learning (including strategy use), the transferability or generalizability of learning, and the importance of the context for learning are interrelated areas that have received much attention in cognitive research. This paper can only touch upon a few of the many recent examples of writing related to these important ideas.

An adept learner makes use of cognitive strategies for learning and makes use of metacognitive strategies to monitor his or her progress (Pressley, Goodchild, Fleet, Zajchowski, & Evans, 1989, Paris, 1988). A strategy is "an ordered sequence of mental steps enacted to satisfy a goal" (Lehrer, 1989, p. 303). In order to learn adeptly, the learner must first know some strategies, but – of equal or greater importance – he or she must also know how and when to apply them.

The investigation of strategy use is now a major topic in cognitive research. Can strategies be taught? (Pressley, Forrest-Pressley, Elliot-Faust, & Miller, 1985). Why are people not strategic when they need to be? (Rothkopf, 1988). How can strategies be taught to promote their generalization or transfer to different situations? (Perkins & Saloman, 1988, 1989). What is the importance of context? (Gardner, 1990). What is the role of basic knowledge? (Hirsch, 1987). Can strategy use or general problem solving ability be enhanced by computer use? (Lehrer, 1989, McCoy, 1991, Papert, 1980).

At this point in time there is not a clear consensus regarding the importance of factual content (how much content? what content?) in relation to strategy use and the generalizability of learning. The issue has become somewhat polarized and is regarded by some as requiring the choice between cultural literacy and critical thinking. For example, Hirsch (1987) views the basic knowledge that makes one culturally literate as something that becomes lost if too much time is spent teaching critical thinking; he is pessimistic about the transfer of learning strategies and general skills. An alternative viewpoint, as expressed by Salomon (1988) and Perkins and Salomon, (1988) is to view both generalizable learning skills and 'local' knowledge as being complementary, and not in competition with each other. Pea and Soloway (1987) hold a similar optimistic view about the relationship between generalizable learning and factual knowledge:

> *The necessity of subject matter knowledge in expertise has been recognized for centuries. What is new is the research-based recognition that it is not a knowledge base of facts per se that should be an instructional goal. Instead, students need to acquire facts, principles, or theories as conceptual tools for reasoning and problem solving that they can see makes sense because they have consequences in meaningful contexts (p. 37).*

Where one stands on this issue clearly influences the types of learning activities that will be deemed appropriate for effective learning.

In summary, the cognitive viewpoint places a research and implementation emphasis on the ways in which an individual can learn how to become a good learner. Context and generalizability of learning are both important factors for consideration. "Learning becomes the grinding of better (conceptual) lenses that help us make more sense of the world." (J.S. Brown, 1989, p. 9).

What does cognitive science tell us about school?

School is certainly one of the most important environments in which cognitive change (or learning) is expected to take place. What can be done in school to promote the learner in his or her quest to make more sense of the world? Particularly as technology now has the potential to provide the learner with access to increasing amounts of information, it is important for school-initiated activities to be arranged in such a way that learners can use that information effectively. How do learners organize, structure, interpret, evaluate and understand the information they will be exposed to in school? How can learning environments (including the people who are part of them) assist with the processes of learning? Schools must respond to many questions posed by a changing world. Those responses should be based on the most current knowledge about the learning processes.

A basic question relating the cognitive perspective to the role of learners within a teaching environment has been addressed by Phil Winne (1985): "The emphasis in the cognitive mediational view of teaching is not on teacher behaviours but rather on students' cognitive interactions with teaching" (p. 673). This quotation refers to the human teacher, but books, video, computer programs, information systems and other media can also fulfil a 'teaching' role. The cognitive view considers effective teaching to be a response to the learning requirements of the individual. The focus is on the learner.

What are some implications of the cognitive viewpoint for educators and learners?

- the learner's present level of understanding is the starting point
- the learner often has alternative conceptual frameworks which frequently interfere with the learning of the desired framework
- prior knowledge should be activated as much as possible
- learners need to be aware of relationships among and between concepts and principles in content
- learners need to be involved and engaged as active participants in the learning process
- learners need to be aware of the effectiveness of their learning strategies.

What can be done to actually implement a learning environment that is consistent with the cognitive viewpoint?

Brown, Collins and Duguid (1988, 1989) discuss authentic versus school activity and describe a "cognitive apprenticeship" as a powerful way to conceive of learning activities. "Apprenticeship" implies the importance of modeling, coaching and 'fading' (or gradual withdrawal of the coaching as the learner gains competency) through authentic activity as well as the importance of social interaction and collaboration. The learner observes and gradually participates fully.

"Knowing (and not just learning)... is inextricably situated in the physical and social context of its acquisition and use. It cannot be extracted from these without being irretrievably transformed" (Brown et al., 1989, p.1). Lewis (1990) explains that a number of cognitive scientists now [illegible] a theory of social interaction which incorporates the effects of cognition should be developed and would replace existing theories of cognition which attempt to incorporate the effects of social interaction. The culture of school, as a social environment, is thus extremely important. As the school environment deviates further and further from the types of environments where students will ultimately use their learning, the more likely it becomes that students will be unable to put their school learning to use.

Real world knowledge is never static, although curricula and learning resources sometimes are:

> *Within a culture, ideas are exchanged and modified and belief systems developed and appropriated in part through conversation and narratives, so these must be promoted, not inhibited. Though these are often anathema to traditional schooling, they are an essential component of social interaction and thus of learning. (Brown et al., 1989, p. 26.)*

These notions challenge much of what happens within the traditional school culture, where information is presented in an abstracted format and used in a way that is usually quite unlike the way it is used by practitioners: "an unacknowledged dependency on such school-based cues makes the learning extremely fragile" (p. 14). "Authenticity in activity is paramount for learning" (p. 15).

Note that the cognitive perspective as described by Brown is considered to be an extreme view by some other cognitive scientists such as Merrill, Li, and Jones (1990) and Nickerson (1988) who prefer a conservative constructivist view as described in the following statement: "learning is best described not as a process of assimilating knowledge but as one of constructing mental models. The learner's role is seen as necessarily an active one" (Nickerson, 1988, p. 5). In this view, however, active learning can involve more abstracted formats of knowledge and can (although it does not necessarily have to) take place in a less socially-oriented environment.

From both the conservative and more extreme cognitive viewpoints, the learner is no longer viewed as a *tabula rasa*. For this reason, cognitive theorists consider it desirable for the role of the teacher to move away from that of information transmitter. The next few paragraphs will briefly describe a small sample of similar cognitive perspectives relating to the school environment.

Newman, Griffin and Cole, have entitled their 1989 book *The Construction Zone: Working for Cognitive Change in School*. The premise of this book is that school can be a 'construction zone,' or place for the meeting of minds, where "complex shared activity . . . allows one mind to appropriate another's thinking and that provokes new meanings" (p. xiv). It is important to note here that the "mind" being met by the learner could be a teacher, a book, another child, etc., and that the "meeting" could be face-to-face or through media such as telecommunications. They describe how the consideration of the interaction of social and individual processes leading to cognitive changes can have a profound impact on how the teacher makes decisions, when the teacher intervenes, and the type of evaluation and assessment that takes place in the classroom. The social construction of knowledge is a model that allows for a degree of creative change that is not accommodated in the knowledge transmission model of education.

Garner (1990) discusses the inappropriateness of the traditional classroom situation in promoting cognitive and metacognitive strategy use. Because the performance orientation of many such classrooms rewards a type of success that can be defined as outperforming others with the least possible effort, students develop superficial strategies that may be immediately effective but they are not the type of strategies that really relate to the process of learning. This is especially important to consider when attempting to encourage learners to be self-directed or to transfer their learning to new but related situations. The competitive classroom is thus a barrier to learners' motivation in constructing, refining and using strategies: "without high self-esteem and the tendency to attribute success and failure to their level of effort, both children and adults are unlikely to initiate or persist at strategic activity" (p. 521).

Pea and Soloway, (1987), in a report prepared for the U.S. Office of Technology Assessment, summarize what has been learned from cognitive research. They state compelling evidence of a need to move away from the knowledge transmission model of education and revitalize the deeply-troubled school system. They conclude that in the present system, students are unable to utilize their knowledge for reasoning and problem solving and they are also unable to take advantage of the potential offered by technology in support of learning, reasoning, communicating and collaborating.

From the perspective of cognitive science, we have now defined the ideal learning situation as one where the learner can function in a self-motivated manner to actively acquire and use information from all kinds of sources, where the learner is encouraged to apply strategies and monitor them for their effectiveness, and where the learner works to construct individually relevant meaning. A powerful context for the construction of meaning involves the authentic culture and social interactions of a cognitive apprenticeship. The information-rich world of telecommunications seems to have the potential to be an appropriate environment for both acquisition of information and social interactions (Teles, 1991). What are some of the important considerations?

Information Overload

Earlier in this paper there was a description of what cognitive science tells us about learning. A central concept is the learner's mediation or the interaction and integration of new information with a pre-existing world view. Mediation implies selective attention, which is not a new concept. We know intuitively that we are usually able to screen incoming but unwanted information, such as the background noise in a room when we are trying to hold a conversation. Mediation and selective attention in learning, however, are gaining importance as a topic of study, as more and more information is becoming available in the learning environment. Selective attention is required to avoid cognitive overload. What is the important information to select? How can learners acquire the judgment to effectively select information?

Relan, (1991) describes how in an "open-ended environment, decision-making may contribute to an unforeseen cognitive overload" (p. 12) but goes on to state that "placing vast amounts of networked information and open-ended tools at the learners' disposal encourages them to generate novel solutions to criterion tasks, enhancing their creativity and problem-solving tasks" (p. 13) explaining that "devices which monitor learners' actions should be constantly available" (p. 13). The 'devices' refer to feedback mechanisms, strategy guides and navigational help. "It would be the instructional designer's chore to make learning more manageable, especially to novice users of the environment" (p. 13).

O'Shaughnessy, Coskuntuna, and Kantro (1987) concluded from experimental evidence gathered in an information environment that "people continually circumvent the overload problem by developing strategies to selectively choose the information they need and ignore other information" (p. 61). The importance of strategy use has been addressed earlier in this paper, but it should be re-emphasized in relation to the cognitive overload of information systems. All too often, learners misuse or neglect to use strategies, even when they know them. Telecommunications and information systems are very new to our society and to our education system; therefore effective strategies (for instance, in hypermedia use) are not fully developed. Context again appears as a major issue. These authors state that there is a "problem for people who are gathering information they are not familiar with: they consider a large number of attributes to be important, but they are limited in the amount of attributes they can consider" (p. 66). This has a definite implication for the structuring of on-line information retrieval and decision support systems.

DiSessa (1988) discusses a misleading aspect of the information explosion: "The mistaken attitude is that all it takes is a mastery of a properly organized collection of facts. Instead, learning is better viewed as conceptual change" (p. 47). In a similar vein, Pea and Soloway (1987) state that

> *. . . information access does not make education. Students need to formulate inquiries that information search may play a role in and then to know how to filter and organize the information they obtain through searches in order to address the questions that led them to their initial search. Students will need special browsing tools for examining large information databases designed to take account of features of their understanding and of learning environments. Cognitive and instructional research . . . needs to be extended so that we know more how students can learn to synthesize information from diverse sources collected for a variety of purposes. How should searches and inquiries be formulated? What are the information age equivalents to what used to be taught as library skills? (p. 58).*

As in the Phase I SITP interim report (where teachers have requested structures to help them with classroom management and curricular links in the context of a rich information-access environment), there is a need expressed by teachers to find ways of helping learners interpret, evaluate and use information through effective and meaningful activities.

Cognitive science, technology and education

The need for devising appropriate activities to meet the cognitive requirements for learning in a technological environment seems obvious. In the literature, there are a few examples where the technology has been used within a deliberate theoretical framework.

The first three of the following examples focus on technology as a way of presenting information and helping individual learners make best use of it. The remaining examples deal more with environments where collaborative learning is encouraged through the use of technology.

Cognitive theory as a basis for using technology in information presentation

Smaldino and Thompson (1990) discuss Gagne's nine events of instruction (Gagne & Briggs, 1979) as a framework for structuring the use of computer technology (in this case, software used in a science unit). Various types of software (such as simulations and tutorials) and hardware (such as LCD projectors) are described as appropriate to the following steps of learning:

- gaining attention
- informing the learner of the objective
- stimulating recall of earlier learning
- presenting new material
- providing learning guidance
- eliciting performance
- providing feedback about performance
- assessment of performance
- enhancing retention and transfer.

The above is very teacher-directed, although similar guidelines could be developed for a more learner-focused experience.

Kozma (1987) describes learning tools in relation to what is known about the limitations of human cognition. The computer is seen as a cognitive tool which can amplify, extend or enhance human cognition. Activities are open-ended and learner-controlled within a system that defines or structures the work space such that learning-related skills and strategies are more likely to be activated (p. 21). The system "supplements working memory . . .

- makes relevant, previously learned information available simultaneously with the acquisition of new information
- promotes learner to structure, integrate and interconnect new ideas with previous ones" (p. 23).

The STUDY system presented by Phil Winne (in press) at the Literacy and Technology Symposium at the University of Victoria (1991) is another example of a technology-based learning environment based on an instructional theory. In this case, the theory casts the learner as artisan, cognitively processing knowledge to create and use knowledge structures.

Collaborative learning, cognitive theory and technology

Mason (1988) describes computer conferencing as a learning environment in tune with the objectives of self-directed learning, because

- *learning is a process of expanding upon what the learner already knows*
- *the learner becomes an active seeker, responsible for finding out what he already knows and what he needs to learn*
- *by formulating what he knows and communicating it to his peers, the learner contributes both to his own learning and to that of others*
- *through discussion which grows from the commitment of the group, each individual engages his own desire to learn (p. 30).*

However, the reader is cautioned that

> *. . . when attempting to displace the teacher from centre stage and hand over the responsibility for learning to the student, the innovator often finds not grateful thanks, but great resistance. For years, students have been accustomed to authoritarian teachers, to the system and .. an educational milieu in which they accept the role of passive, dependent, competitive learner. Consequently, they lack confidence in their own judgement (p. 30).*

Mason considers the on-line environment to be appropriate to a theory of autonomous learning, because conferencing helps to "de-package knowledge" (p. 38), starting with what the learner knows and allowing for peer support.

Scardamalia and Bereiter (1989) have designed a Computer Supported Intentional Learning Environment (CSILE) on the basis of cognitive theory incorporating communal knowledge building and strategy use. CSILE is a networked computer environment in which students can share information and build collective databases.

J.S. Brown (1985) discusses process versus product as an important cognitive context for using communal and informal electronic learning tools. One example is a set of tools for multiple authorship, which can keep track of all revisions of a written work and allow each author to comment and leave messages for the others. Another is a structure for community information systems, so that specialized 'subcultures' of learning can develop across a broader geographical base of learners than is currently possible. "The right collection of tools should help the overall system to act as a mirror for the user's thought processes, enabling him to reflect on his own thinking and improve his metacognitive skills" (p. 199).

"One of the main differences heretofore between formal education and professional work has been that cooperative effort usually characterizes the workplace, while most students do solitary exercises. CMC opens up the possibility for a great deal more collaborative work in education." (Boyd, 1990, p. 274).

Nipper (1989) describes how CMC has the potential to "overcome the problem of social distance between learners and teachers, not just geographical distance" and concludes that although there will be difficulties (for teachers in particular) because of the changing roles, "computer conferencing may contribute to less authoritarian concepts of learning and teaching" (p. 71).

What else can the cognitive perspective tell us?

Many other reports of technology in education describe activities that do promote strategy use, encourage collaboration and support cognitive change without specifically taking the cognitive theoretical perspective. A small number of these, specifically related to computer mediated communications, will be described later in this paper, in the section entitled A sample of applications of CMC.

So far, we have considered the cognitive perspective in relation to fairly general educational activities, some of which incorporate computer technology. Cognitive science also informs the more specific ways in which human beings interact with machines such as computers. Issues such as how the learner has constructed an underlying mental model of a computer system can influence whether or not that system is used effectively. A fairly large body of research, much of it gathered outside of the educational environment, exists in this area. Frye, Littman, and Soloway (1988) describe the situation as follows: "even though human-computer interaction is a topic of growing interest, that field has not focused on the special properties of educational software" (p. 451). The next section of this paper will describe some of the human-computer interaction (HCI) research.

Cognitive science, information theory and human-computer issues

The importance of the application of a cognitive perspective to human-computer and information science issues has been expressed by More (1990) "In a psychological sense we need to recognize the importance of human factors in designing, accepting and applying new systems" (p. 318), by Williges (1987) "Due to the complexity of the human, task, hardware, software, and environment configurations, the designer must simultaneously consider a variety of factors that affect multiple dimensions of system performance" (p. 67), and by many others.

Such work has been seen as quite fruitful: "one of the unique features of such suggestions (from the cognitive view of information science) is that many of the ideas which have been couched initially in abstract or polemic terms have subsequently led to theoretical, experimental and practical advances in a broad range of information science activities" (Belkin, 1990, p. 11) or as an incomplete improvement over previous attempts:

> *There are four basic reasons why systems are not working well: current systems tend to be designed in haste and without adequate developmental testing, current systems tend to be pushed through production and sales too rapidly, inadequate attention is given during design to the details of the human computer interface, inadequate attention is given to operational test and evaluation systems before systems are presented to the public . . . it is understandable that excitement and anticipation sometimes replaces objectivity (Muckler, 1987, p. 4).*

In a review of Nigel Tucker's 1989 book, *Interactive Media: The Human Issues*, Ford states that "optimism must be tempered by the thought that the real prerequisites of significant advance are a knowledge of the sensitive interactions between human, cultural and technological aspects of learning which still elude us" (Ford, 1990, p. 343).

Interface issues

Reports from Phase I of the SITP have indicated that the current interface has, in fact, been a stumbling point for at least some of the participants. This section is an attempt to cover a small portion of the current thinking about appropriate directions in interface design.

Graesser, Gordon, Forsythe, and Greer (1991) define 'educational artifacts' as a category of devices designed to promote learning and describe the relation of cognitive theory to person-artifact interfaces. "A good interface would cater to the constraints of human cognition; the interface would minimize the time to perform tasks and the incidence of user errors" (p. 16). Since the educational activities (perhaps a creative writing experience or formulating a question to ask an expert) involving telecommunications require a great deal of cognitive processing, it becomes even more important that the interface be as transparent as possible. The effort spent in correcting an error such as getting lost in the system will obviously take away from the effort spent in making thoughtful use of the information that can be acquired through the system.

Rosson and Alpert (1990) state:

> *In the solution of an interactive software design problem, an important component is the designer's model of how the user will understand the*

system . . . we refer to this as the design model; the user's actual understanding is termed the conceptual model. The design model is comprised of the entities, operations, and relations that the designer expects (or hopes) the user will refer to when working with or reasoning about the system. Usability will be improved to the extent that the designer can create a design model that will lead to a coherent and comprehensive conceptual model. . . . Researchers in user interface design have proposed a variety of techniques for building effective design models and evoking the corresponding conceptual models in users. (pp. 352-3).

Such techniques include providing training manuals and advance organizers, creating interfaces that make use of analogies or metaphors and thus relate a system to something already familiar to the user, sometimes even designing intentionally limited computer systems that mimic real-world systems and are therefore more intuitive to the user. These authors conclude that the latter is not really a desirable design technique because emulating a non-computer environment does not allow the designer to make use of the real power of the computer.

The user's conceptual model describes his or her understanding of what the system can do, and how to move through the system (navigation) to actually do those things.

Nipper (1989) states:

Poor navigation tools, or lack of structural transparency, is a common constraint in computer conferencing systems as we know them today... such constraints in general may increase the problems of the ordinary distance learners, who have no prior experience of CMC, and therefore possess no tools or measures whereby they can organize the learning situation. The use of the system may subsequently be very unstructured and educationally inefficient. (p. 68)

Streitz (1987) considers human computer interaction to be a type of "interactive problem solving" (p. 77) and describes how the problem solver must build up a mental representation of the problem based on both previous conceptual models and incoming information. In order to provide a system with appropriate information, both the designer's and the user's models must coincide, or be 'cognitively compatible.' In order to achieve this, the designer must ask, "What are the relevant properties of the interface which allow a novice user to build up a compatible initial knowledge representation?" and "How can one provide transfer of learning from a mode suited to the novice to another mode for a user who has acquired expertise?" (p. 78).

Streitz continues to describe interfaces as being of two types: dialogue mode or metaphor world. Dialogue mode involves user-initiated commands while metaphor worlds often involve such options as menus and can be considered to be system-initiated. The former requires recall (to generate the exact command lines) while the latter requires only recognition (selecting the correct menu option). Metaphor worlds are therefore cognitively much less demanding. An interesting result of this experimental study was that users selected the cognitively more demanding dialogue mode as they gained expertise with the system. This phenomenon was also observed in Phase I of SITP, and seems (in both cases) to be related to a lack of power and flexibility in the particular menu-driven interfaces involved.

A similar perspective is taken by Relan (1991) who describes the desktop interface (which fits the above definition of metaphor world) in relation to the need for a greater cognitive approach in computer-based instruction. Relan states that the desktop interface increases interactivity, allows greater learner control, relates to learning styles by incorporating both visuals and text, and allows learning strategies or cueing to be embedded in software design.

These characteristics are described as not being necessarily desirable in all situations, and Relan suggests possible options:

. . . learners should be given control, but if they do not make good use of it, the program should intervene and lead the student through instruction . . . [or] . . . where students are provided with advisement on their current instructional

need, which is iteratively updated statistically by the program . . . the option to act on the prescription is left to the student. (p. 12)

Another finding of Relan's (that might be related to Streitz's experimental results indicating increased expertise led to different choices in interface use) was that "for novice users, visuals are processed more quickly than text; however, this advantage is neutralized as users become more familiar with text" (p. 10).

Belkin (1990) describes promising work from the field of information technology. Within the context of a library communication and information retrieval system, and applying a cognitive perspective, where the users' state of knowledge is the framework for computer architecture, he describes studies where "the cognitive viewpoint led to the specification of the functionality and architecture of intelligent computer-based information systems" (p. 14). Here, designers based a system on "general characteristics of librarian and user searching behaviour, which they could relate explicitly to the choice of mediating knowledge structure on the part of the librarian" (p. 13). This information, gathered by a "thinking aloud" methodology, also incorporated a model of the user, a model of the actual documents being sought and ultimately led to a relational model among librarian, user and documents. Here, user requirements were apparently structured in a way that could be understood by the designers, who could in turn create a system that incorporated the user's conceptual models.

Hildreth (1989) discusses intelligent interfaces and intelligent retrieval systems, and states that interface issues cannot be handled separately from the internal workings of the system: "this author has seen too many bad query-language indexing and retrieval design implementations that could not be improved or glossed-over with any amount of 'front-end' software" (p. 51). User requirements are an important consideration: "A single search interface and a single retrieval model (e.g. Boolean) are not adequate for the variety of searchers and search needs that exist" (p. 105). and system intelligence is seen as being of two types: delegation (or supplantation), where the system makes decisions based on pre-programmed criteria, and augmentation (or consultation), where the machine assists the user but does not make its own decisions. State-of-the-art information retrieval systems include features such as natural language query input, linguistic analysis of input, graphic aids to browsing, probabilistic retrieval (weighted logic and ranked output), and provide feedback to the user to encourage search strategy modification.

Frye, Littman, and Soloway, (1988) discuss the interface issue from the perspective of intelligent tutoring systems, pointing out that the interface is more important in educational situations than elsewhere for several reasons:

> *. . . the interface must provide an entry to the content domain rather than vice versa. In other types of software, the user typically knows what application a program is meant to have and can use that knowledge to decipher the interface . . . users of educational software will not have a similar advantage. They will not have a good understanding of the domain being taught and so will not have that entry to the interface . . . A further requirement for an interface to a piece of educational software is that it must be sensitive to the student's general knowledge and/or developmental level. Given that the interface must introduce the user to the domain, and not the reverse, the interface will need to provide for variations in the skills of different users. (pp. 452-3)*

Of interface studies, Frye et al. (1988) is one of the few that considered the educational environment as having distinct characteristics. These authors conclude that an evaluation of students' cognitive processes should be the basis for the user interface. Recognizing that this may often seem difficult in a practical sense, the argument for continuing to attempt to develop such an evaluation or model is simply that it will lead to more usable and effective computer-based learning environments.

Hypermedia interface issues

The interface issue cannot be complete without a consideration of hypermedia. When articles are being written with titles such as "Lost in Hyperspace: Cognitive mapping and navigation in a hypertext environment" (Edwards & Hardman, 1989) it is obvious that the cognitive approach to interface design is also being applied to the structurally complex 'hyper' environments.

Maule (1990) in a short article entitled "A review of current research in hypermedia information design," describes the human-computer interface to the hypermedia environment as being "a kind of discourse for which no agreed-upon model exists . . . futurists project a time of 'intelligent' graphical interfaces, capable of maintaining and applying information about users to increase the effectiveness of the systems" (p. 7).

In *The Interactive Learning Revolution* (Barker & Tucker, 1990), the perspective is taken that "the user is back in control because the computer has been tamed . . . digital technologies . . . will unlock the knowledge bases of the world" (p. 15), and describe how "educators and trainers have leaped to the conclusion that interactive multimedia was invented solely for them. Not so! . . . [it is] . . . the future interface of the next generation of personal computers" (p. 21).

Jonassen and Wang (in Branyon-Broadbent & Wood, 1990) define hypermedia as

> *. . . a soft technology for organizing and storing information in a knowledge base to be accessed and generated nonsequentially by authors and users . . . although hypermedia did not evolve as an instructional medium, its characteristics mimic the associative properties of the mind, making it a potentially powerful new learning technology. (p. 156)*

Although generally enthusiastic about the ability of hypermedia to provide an environment for learners that is conducive to many types of learning (including information retrieval, knowledge building and restructuring, and problem solving), these authors clearly acknowledge the potential of the hypermedia environment to create difficulties in navigation, and cognitive overload for the user.

> *The number of learning options available places on learners increased cognitive demands that they are often unable to fulfil. Hypermedia browsers must be able to monitor their own comprehension of the information presented in the hypermedia, select appropriate strategies for correcting any misconceptions, and develop information-seeking strategies that facilitate integrating information and synthesizing information from the hypermedia. These are known as meta-cognitive strategies, and they require additional effort on the part of the browser. We know that good learners use them and that poor learners do not. Browsing hypermedia places significant demands upon the user, demands that may take energy from the more important process of learning. (pp. 161-2)*

Jonassen and Wang (1990) also discuss the issue of learner control (which was similarly addressed by Relan earlier in this section) and state that "the research on learner control has not generally supported any learning benefits. This is especially true with average and below-average learners" (p. 162). Here, it seems, is a suggestion that cognitive and meta-cognitive strategies (acquired almost magically by "good learners") cannot be encouraged in poor learners, and that the only answer is to facilitate learning by giving control either to a teacher or to a structured system. In fact, we are back to the earlier debates raised in the section of the paper entitled: What does cognitive science tell us about learning? What is the status of strategy use, especially regarding generalization and transfer? Clearly, learners lacking a system of strategy use will become lost if given control in an unstructured environment (as hypermedia often is), but the question (or perhaps the challenge) remains: do we measure success by the amount of content acquired? Or by the learning strategies developed?

In summary, research indicates that an appropriate interface seems to have the potential to facilitate strategy use. There are many reasons why interfaces should therefore be designed to do so to the greatest extent possible. For hypermedia systems in particular, because they are designed to link ideas in a way that will not be familiar to many learners, it becomes even more important to ensure that the learner has some way of synthesizing, interpreting and using the information available. Perhaps it is appropriate at this point to re-acknowledge and emphasize the ideas expressed by Brown (1989), and Brown, Collins, and Duguid (1988, 1989), described in the section of this paper entitled: What does cognitive science tell us about school? How can we best provide an authentic learning experience for children?

The next major section of this paper (Impact of technology, information systems and telecommunications) will describe how technology (particularly information technology) is likely to be part of the real-world environment for most children--if not right now then very soon. It is even more likely to be prevalent by the time they reach the workplace. The argument that technology is part of an authentic learning environment is quite convincing.

From the literature reviewed on interface issues, there seems to be a common message relating to users of a technological (or any other) learning environment. This message is derived from a cognitive perspective, and can be simply stated: design the interface based on an understanding of the user's mental model(s). Note that this does not confine the designer to replicating (through technology) functions that the user is already familiar with. It does not make sense to evaluate the feasibility of a proposed bridge based on an observation of the number of people who swim across the river at that particular point (Lewis, 1990). What designers must be aware of is how (or whether) users will be able to incorporate the features of a new system into their existing model of the world.

It is almost surprising to find a consistent message across research that is derived from such diverse technology users as highly motivated library technologists, office workers, distance education students and very young learners. In summary, the cognitive perspective of human-computer interface seems to be fairly robust. It is less clear whether there is (or will be) any definitive answers regarding the "Ideal Interface," how to identify user preferences, or how to determine the optimum degree of learner control. Much of the literature suggests that what a user requires from a system changes as he or she gains expertise, and that a single user might apply different strategies for interacting with a system in different situations. There is probably a message here about the need for flexible systems and further study of the effectiveness of such systems.

Summary of the cognitive perspective

To summarize, the cognitive perspective always makes reference to the individual and to his or her interaction with information. An understanding of the individual, the information, and the context in which that information will be acquired and used can facilitate the design of learning activities and learning environments, including environments which require a human-computer interface.

Impact of Technology, Information Systems and Telecommunications

There is an abundance of literature, both popular and scholarly, that addresses the ways in which the increased access to information will impact our society. For example, Tiffin (1990) states that "Over the next decade, telecommunications will affect every aspect of developed societies including education"," and More (1990) describes the changes to our economy and the new thinking tools that will be required:

> *Many governments have begun to recognize – some would argue, rather belatedly – that a nation's very economic performance will be critically affected by success in mastering, exploiting and marketing new developments in information technology and systems. The critical factor, however, is not technology or economics alone, but rather the human factor involved . . . information systems are both culturally determined and culture-determining. (pp. 311-2)*

Perhaps the attitudes, skills and knowledge needed for participation in the information age can be acquired by students through a traditional curriculum. Perhaps it is the responsibility of industry to equip workers to meet the specialized requirements of the workplace. If these statements are true, there might still be reasons for using information systems and computer mediated communications in the classroom, but in this section of the paper, literature will be presented that indicates that the traditional curriculum does not adequately prepare students to take their place as functioning adults in an information society, nor does it provide them with the ability to make use of specialized training environments that they will encounter when they reach the workplace.

For instance, Berryman (1990) states that in the fast-changing labour market (where job requirements are changing more rapidly than ever because of advances in technology) there is an increased need for learners to develop lifelong learning skills. "Employer sponsored training reinforces rather than reduces the differences in educational attainment among employees. Well educated people are not only the most likely to find employment, but also the most likely to receive training from their employers" (p. 38). This article also stresses some of the same ideas expressed in other parts of this literature review, including the need for learning to take place in an authentic context, the need for learners to work collaboratively and with the same kinds of assistance they will have in an authentic environment, and the need for learners to become effective problem-solvers and strategy users.

McClintock (1988) states that because of computer technology we are undergoing a "transformation of a culture of memory to one of intelligence . . . people have begun to learn how to process intelligently the information they need through objects external to living minds" p. 351).

A perspective similar to both Berryman and McClintock is taken by Dede (1987, 1989) who states that

> *. . . human strengths in partnerships between people and cognition enhancers involve skills such as creativity, flexibility, decision making given incomplete data, complex pattern recognition, information evaluation/synthesis, and holistic thinking. Such higher-order mental attributes might become a new definition of human intelligence . . . the goal of teaching the basics would shift from performance fluency to*

providing a cognitive underpinning for sophisticated problem recognition and unusual problem solving . . . 'learning while doing' would become a more significant component of education because combined computer and telecommunications technologies allow delivery of instructional services in a decentralized manner. (p. 23)

Very recent articles in *Canadian Business Magazine*, such as Allan (1991), Ziedenberg (1991), and Litchfield (1991) also describe a technologically sophisticated workplace that now demands and will continue to demand workers with greater higher-order thinking and literacy skills that the education system is currently able to produce. Clearly, there is a message from many sources that technology is having an impact that reaches into the classroom.

Emihovich (1990) describes the metacognitive skills provided by a computer environment as 'cultural capital,' and states that "those who lack this resource will fall further and further behind" (p. 232). But how should the computer environment be structured? How will we ensure equity of access to these important skills across gender, socio-economic or other types of barriers?

Why get kids involved in telecommunications or information technology?

It would be very effective at this point in the literature review to cite a few definitive studies that indicate how computer-mediated communications or information technology can be incorporated into a variety of curriculum areas with the ultimate result of providing learners with better learning strategies, increased collaborative abilities, more higher-order thinking experiences, improved problem solving and so on. At present, such studies do not seem to exist. The audience for CMC and IT up to this point has typically been the university student in a distance education course, and it can be argued that results of existing implementations may not be generalizable to other groups. Unfortunately (or perhaps tantalizingly), there are more questions and hopes than answers at this point in time.

For instance, there is the eloquent question: "what can be done with computer-mediated communications that will be really valuable educationally in our complex, highly interdependent, uncertain world?" formulated by Boyd (1990, p. 271). Boyd's paper describes five generations of computer-mediated communications, and explains that most of the educational applications today are still at the level of the first generation. First generation CMC includes messaging, conferencing and information access without the evaluation, animation, graphics, sound and high level logic (e.g., intelligent keyword searching, automatic logical insertion of topics pointers, etc.) that are included as second generation functions. Third generation CMC includes first and second generation functions, but also incorporates structures to support cooperative work systems (e.g., distributed editing). Fourth and fifth generation CMC include virtual environments and will "provide participatory and anticipatory learning opportunities which will empower people to deal rationally, and perhaps beautifully, with the challenges of complexity and uncertainty" (p. 273).

The next section of this literature review will describe some of the actual educational applications of computer-mediated communications and information technology.

A sample of educational applications of CMC and IT

Recent issues of *The Computing Teacher* have a section devoted to classroom experiences in the implementation of telecommunications (for example, Rogers, Andres, Jacks, & Clausen, 1990, Lake, 1989-90, and Kurshan, 1990). These are typical of various other reports (including Thompson, 1990, Yurkovick, 1989, Waugh & Levin, 1989, and Goldberg, 1988) and ISTE, USWest and similar telecommunications publications, which either describe technical network issues (features of various networking systems, hardware requirements and so on) or describe what was done in particular classrooms (or distance education environments) and offer guidelines (such as lesson plans) for others who want to do similar things. Often these reports include testimonials describing how motivating and horizon-expanding the experience was, as well as cautions about the possible pitfalls and black holes that can be encountered. This type of literature tends to lack objective evaluation of the educational impact, probably because it is all so very new. This literature does, however, quite often relate specifically to the public school learner who is the target audience for the SITP.

Another type of literature discusses educational (and other) paradigm shifts brought about through the use of conferencing systems and information technologies (for instance, Harasim, 1990, Mason, 1988, 1989, and Romiszkowski, 1990); in a telecommunications environment, the content or quality of information (such as a message in a conference) becomes more important than the status or personal characteristics of the source; new information technologies include cooperative knowledge bases which allow users to add and access information at any level of detail desired. Through telecommunications, the roles of instructors and students are much less distinct than in traditional classrooms. This literature is based on thoughtful observations of the apparent effect of the new technologies, but even here, the impact on learning is not usually objectively explored. This literature tends to deal with college or graduate level students. For instance, although Romiszkowski mentions that the implementation of such technology should reach down to at least high school, he feels it is less likely to have impact at the elementary level, mainly for social reasons. Teles (1991), however, has successfully used audio conferencing with children as young as Grade 6, and describes its value as an interactive learning tool.

Perhaps (as has been the case with the early phases of many innovations), the somewhat subjective initial reactions to computer-mediated communications or information technology-oriented learning environments will form the basis for a more in-depth analysis of the positive and negative impact on learning and will eventually lead to the development of increasingly effective CMC and IT activities.

A third type of literature describes some of the frameworks that have been developed to guide the inclusion of CMC and IT in public school curriculums. It is perhaps worth noting that in these examples, the technology is specifically related to cross-curricular goals for learning and that there are clear implications regarding the evaluation of effectiveness.

Van Weering and Plomp (1991) describe how information and computer literacy (ICL) is now (based on the recommendations of a committee formed in 1987) being included in the curriculum for Grades 7 to 9 students in the Netherlands. The stated objectives, relating to information technology (IT) and computer use, are as follow:

(1) *students develop insight into processes of purposeful data collection, processing and retrieval, and are able to deal with data and information in a way that demonstrates understanding;*
(2) *students have correct functional pictures of data processing systems (such as the computer) and, on the basis of these, can use the systems;*
(3) *students know how and where IT is being applied, and are able to use various applications of IT;*
4) *students have insight into the social impact of IT. (p. 18)*

"Problem solving is still one of the most important feature of ICL, however, no longer in the sense of solving a problem with respect to programming, but instead in being able to find information by using appropriate new information technologies" (p. 21). The above goals are to be met through integration with the curriculum, and although preparatory skills can be provided through a separate course, the majority of ICL experience is gained through participation in other coursework such as math, science, language arts, social studies, technology and arts.

J.S.A. Anderson (1991) describes the cross-curricular IT competency that Northern Ireland introduced in 1990 as a statutory element in compulsory schooling for students aged 4 to 16. The five objectives are incorporated into the following statement:

Pupils should be able to make appropriate and effective use of IT to:
- *develop, modify and communicate ideas;*
- *create, collect, store, retrieve, validate, change, interpret and present information;*
- *manipulate, investigate and create models of situation;*
- *measure and control elements of the physical environment; evaluate the impact of IT on themselves, other individuals, organizations and society.*

These objectives are to be wholly or mainly delivered through the teaching of the contributory subjects of the curriculum; their attainment by pupils is to be assessed in the context of the use of IT as a tool in the contributory subject. (p. 23)

Students are assessed for competency with reference to 10 levels of attainment.

North (1991) describes the challenges faced by the staff of schools in Northern Ireland relating to the development of effective implementation strategies including staff development and the accommodation of cross-curricular linkages. This project is obviously in an early stage, and one anticipated outcome is that the integration of IT will be a catalyst for fundamental changes to the curriculum.

These varying types of literature (and there are probably many other 'types' that have not been described) suggest that many educators are enthused about using CMC and IT in the educational environment in different ways and for different reasons. Almost everyone involved has experienced frustration of some sort. Evaluation of such projects ranges from the extremely subjective to the relatively structured. Some of the rationales for CMC and IT educational projects have been developed by an individual or small group of teachers; others have been developed through the consensus of a large group and are being implemented at a national level.

How shall we interpret the status of educational CMC and IT?

The types of implementation projects described in the previous section seem to point out that CMC and IT have characteristics that have convinced a number of educators to view them as being very important technologies for educational purposes. Some educators are scrambling to tame these technologies so that they can use them effectively. Since such projects are still in the early stages, problems and unresolved issues are to be expected and many new questions are likely to arise.

The current status

Scardamalia and Bereiter (1989) discuss the growing body of projects in which students link electronically to other schools or countries, to large databases or to experts. These authors describe two types of problems:

> *1. the filter problem . . . ways must be found to reduce redundancy, to sort out questions that can be answered locally or inexpensively . . . and generally to make every demand on the network count for as much as possible . . . [and] 2. the inquiry upgrading problem . . . which states that learners involved in media systems must first engage in serious thought and study, and not expect the 'experts' to do their work for them. (pp. 14-15)*

In a discussion of computer-mediated communication in education, Boyd (1990) states, "it is sometimes quite important to restrict the facilities available for a given course or lesson to the smallest subset of those available, the ones which are really needed, so that participants will not be distracted by 'noise' or frequent calls upon them to make really unnecessary decisions" (p 271).

The comments above suggest that CMC and IT activities should be purposeful and clearly related to the kinds of learning that have been described in the 'cognition' section of this paper. Not all questions require the answer of a distant expert. In some cases, collaboration might be just as effective across the hall as across the ocean. Learning requires the active construction of knowledge--not just the receipt of a canned answer from an expert. A confusing computer system can detract from the educational purpose of the activity.

The future

Perhaps the first type of place to enquire about the future of computer mediated communications and information technologies should be a 'think tank' such as Xerox's Palo Alto Research Center (PARC). "PARC scientists believe that information retrieval and use will be to the 1990s what text editing was to the 1980s. Information retrieval is not an end in itself, but part of some larger activity" (Clarkson, 1991, p. 278). What are the 'larger activities' in education that can make use of the benefits of CMC and IT? The future almost certainly includes continued research and work to come to a better understanding of how CMC and IT have an impact on learning. As some questions are answered, more will be identified. This section raises possible questions for current research projects; in particular it addresses questions that are not mentioned in other parts of the paper.

Nipper (1989) claims that "distance education has always advantaged the highly motivated, and often educationally privileged adult learner. In important respects, this feature is exaggerated even further by CMC" (p. 72). Does this indicate that such technology is inappropriate for the less privileged younger learner? Are there ways in which CMC activities can be designed to accommodate less motivated learners?

Muckler (1987) suggests that literature retrieval "systems claim to heighten productivity without a clear definition or supporting data on what is meant by productivity" (p. 9) and forms some "questions for future systems: Does the new system help get the work done? Is the system really productive? To know this we must carefully define productivity and measure it. And be prepared for disappointment. Should we allow enthusiasm to substitute for performance?" (p.11). Muckler's paper does not limit its focus to the educational use of CMC, but it seems that the notion of the 'work' of learning, the necessity of defining 'productivity,' and the caution against unsubstantiated enthusiasm are all concepts that can be appropriately applied to education. How can we measure educational productivity? Is enthusiasm always a positive factor in education?

If, as Somekh (1989) describes, "one of the main problems [of CMC] lies in getting people to use it" (p. 242), it may be a problem of raising their awareness or it may be that the educational advantages do not yet outweigh the disadvantages. Chesebro & Bonsall (1989) offer a critique of the information society, including the statement that "massive quantities of data are slowly being defined as information and ultimately as knowledge, and the consumption of mass quantities of information is being equated with understanding" (p. 235). A similar critique is offered by Sless (1985): "it is readily obvious that more efficient forms of information transmission are not necessarily going to lead to better communication, but to more, though undoubtedly faster, misunderstandings" (p. 112). These criticisms raise some very important questions for educational research. How can educators ensure that CMC and IT will not become a source of frustration or misunderstandings for learners?

Summary of the impact of technology

This section has attempted to provide an overview of the issues related to the use of technology in education. In particular, effort was made to identify some of the questions and concerns generated by the current applications of CMC and IT. In a very real sense, the investigation is just beginning. Pea and Soloway (1987) compare 'folk theories' of medicine in the early 1800's to current 'folk practices' in education and clearly point out the need for educators to acquire and use a more reliable understanding of learning.

> *What transformed medical practice was medical science, requiring the best minds in highly-focused empirical attacks on the nature of disease and biological systems, and the use of the most advanced technologies available, tuned specifically to the problems' dimensions. Understanding the workings of mind in learning in society is one of the major frontiers of science. Until the complexities of education are better appreciated, we cannot expect popular enthusiasm about research and development for educational technologies.* (p. 35)

Perhaps research in educational technologies is not popular, but it can be argued that the education potential of CMC and IT cannot be put to best use until their impact on learning becomes better understood.

Educational Technology Research and Evaluation: Issues and Methods

For this paper, an educational theory will be defined as a system for understanding how some aspect of learning takes place in some type of educational environment. Theories can be supported by the results of research, or they can be disconfirmed or modified through research findings. Unlike the 'folk theories' described by Pea and Soloway in the previous section, valid educational theories must be more than 'patchwork solutions,' or collections of unrelated observations–they must be consistent, coherent and explicit. Valid theories have explanatory power within an identified domain.

A valid theory (which would provide a much-needed framework) for educational technology research would have to incorporate a structure for the formulation of questions about how learning occurs (what are the cognitive and motivational aspects?), questions about the potential roles and functions of technology (is technology a tool? a medium for expression? how does it shape us? where is the locus of control?), and questions about the intended 'outcomes' of the interaction of the learner with the technology. Are we interested in looking at the impact of technology to support narrowly defined learning outcomes, such as improved test achievement, or should we be concerned with more broadly defined outcomes, such as improved problem solving abilities? Research questions that are clearly framed by a theoretical perspective will provide results that are more easily integrated and applied.

All educators operate on the basis of a theoretical perspective, although often they do not explicitly or completely identify the components of the theoretical framework involved. The educator who holds an explicit theory is open to the challenge of having to reformulate that theory when presented with observations or data that do not confirm it. Holding an implicit theory can present problems because it is relatively easy to ignore evidence which contradicts the theory.

Phase I of SITP has been based on a theoretical framework that is largely implicit. There is an assumption that technology can be used to effectively support education, but the concepts described above (learning, functions of technology and intended outcomes) have not been fully identified. This leads to several research issues that must be addressed. The most important of these is the identification of educational expectations against which the effectiveness of technological innovations can be viewed. Other important issues for the project include establishing appropriate focus areas for research and selecting methodologies that are suited to those topics. Some methodologies involve setting up control and treatment groups for comparative purposes, others (involving less intervention) depend on ethnographic observational techniques. The research methodology selected must provide reliable and objective information, as well as maintain credibility with the audience of educators who might ultimately be involved in implementation related to the research results.

This section of the paper will outline some of the educational research issues that could influence the current project. A few general issues and some issues specifically related to technology will be discussed. Methodologies used in research studies that could be related to SITP will be described.

Issues in educational research

Cuban (1984) articulated the sentiments and frustrations of many educators and educational researchers. Over the years, hundreds of research studies have been conducted, yet very few have produced any significant changes in practice. Some fairly recent trends that may help to promote greater overlap between research and practice will be described in this section of the paper.

Validity is an important issue that is closely related to the methodologies of educational research. Classroom teachers might be more willing to implement research findings if they believed that research methodologies provided results applicable to their own situation. A current trend in the design of educational research involves greater teacher participation which seems likely to lead to greater acceptance of research findings.

Naturalistic versus controlled research: can they co-exist?

Frye, Littman, and Soloway (1988) describe the fact that research methods need to evolve in congruence with cognitive theories: "even though educational evaluation is an established field, methodologies have not been developed for evaluating educational systems that attempt to teach students to "understand"–rather than simply to get the right answer" (p. 451).

Methods are being developed that may, in fact, indicate that such change is taking place: "cognitive strategy research is moving away from the lab and into more naturalistic educational settings" (McCormick, Miller, & Pressley, 1989, p. v.).

Symons, Snyder, Cariglia-Bull, and Pressley (1989) describe recent strategy research as being

> *. . . extremely informative about interventions that have real-world utility. One reason is that contemporary strategy researchers and theorists recognize how various research questions about strategy instruction are related to one another. A second reason is that researchers are gaining savvy in designing studies that answer these questions. (p. 17)*

A straightforward research methodology is described: a 'treatment' group participates in particular learning activities, while a control group does not. Outcomes are compared. Although the "complex reciprocal interactions between teachers and students that are not always easily characterized or easily controlled for research purposes" (p. 18) can sometimes be an obstacle to getting clear answers to research questions, there is general agreement that controlled research methods applied in the classroom can yield worthwhile results, particularly when part of a long-term, multi-experiment endeavour.

These authors describe how this can take place:

> *What are good classroom studies like? They are motivated by clearly articulated theories and important instruction issues. Actual teachers carry out the instruction, with teaching occurring over an extended period of time. The studies are true experiments (i.e. there is random assignment of participants to instructed and control conditions). A variety of dependent measures are collected in order to assess the multidimensional impacts of the interventions. (p. 22)*

Laboratory-based learning research is also moving toward more relevant tasks, and when combined with the results of classroom research, there may be real reason for enthusiasm.

Research issues in educational technology

The literature suggests that a comprehensive theory of technology in education has not yet been developed. Describing information technologies in education, the 1989 report of the OECD concludes "There has been little research into how students learn with computers, what they learn when they interact with computer-based materials or how their learning could be improved by the use of the information technologies" (p. 15).

Acker (1989) believes that due to the problems in keeping up with technological changes, implementation of technology must now come first and "theory construction is left for whomever has the time later" (p. 319). The contrasting point of view is presented by Salomon (1989) whose concern is expressed in the following statement: "Are we back to the atheoretical empiricism which has characterized television research a few decades ago?" (p. 250).

Chaiklin, Hedegaard, Navarro, and Pedraza (1990) describe a theory-based approach to computer use in education that includes the following principles:

1. *All educational activities should be organized toward helping students develop a theoretical approach to subject matter*
2. *The motivation for investigating a particular topic in the curriculum should come from the subject matter and the way it has be developed with the students*
3. *Computer use should be embedded as a part of a larger educational program. (pp. 270-1)*

The formulation and application of [educational] goals are aided significantly by having a theoretical perspective about pedagogical practices. (p. 273)

Although, in a fast-changing environment, theories may never even come close to being fully developed before implementation must take place, it seems unproductive to completely abandon the attempt to build on a theoretical framework. The cognitive theories that have been described in this paper, motivational theories, theories of cost effectiveness, theories of change and others might all be appropriate starting points for evaluating the impact of technology.

Frameworks for educational technology research

Research in the use of technology for educational purposes has not always been structured on the foundation of theoretical frameworks. Some of the frameworks used have been less coherent and comprehensive than would be the ideal. The following sections describe examples of some frameworks that have been developed in educational technology. It is possible that some of the ideas from these frameworks could help with the identification of research questions, the formulation of research methodologies, and the establishment of a more complete theoretical perspective for SITP.

Frameworks such as those described in the next section provide categories which help to organize the relevant issues, althougn they do not really achieve the objectives of a valid theory for educational technology. More centralized frameworks, such the ones presented in the following section based on the dimension of cost-effectiveness, can be related to all other dimensions of a research study.

Organizing educational technology research

Pea & Soloway (1987) have addressed the fundamental roles for education science and technology. "Research in the cognitive, social, instructional, and computation sciences has brought about a fundamental change in our thinking about learning and teaching" (p. 30). These authors provide a

. . . framework for organizing the R&D directions considered most promising by experts in the field:

1. *changing what students do;*
2. *changing how we track learning;*
3. *changing what's taught;*
4. *changing what teachers do;*
5. *changing the school environment. (pp. 31-32)*

A different type of research framework is presented by Disessa (1987) to assist in understanding the impact of computers on education. She argues that a real revolution far beyond just "getting computers into schools" is underway which emphasizes the importance of the following issues in planning and research:

- acceptance of complexity (no simple mechanisms of explanation)
- shift in phenomenological focus (to domain specific)
- shift in methodology (new major focus is protocol analysis - moment by moment flow of problem solving activity).

"We must understand education as a complex interacting whole that must reach a new equilibrium in response to the many major perturbations that will be supplied by information technology" (p. 355).

Emihovich (1990) suggests that the following questions are important in a study of computers in education:

Who benefits from computer usage? and its corollary questions, Are these benefits equally distributed? What curricular and staff development changes are required? What changes in teacher-student relationships can be expected? How much control (if any) do teachers have over implementation? and most importantly, What aspects of children's learning do we really desire and expect computers to change? (p. 226)

She discusses some Logo studies that did not show positive effects, and concludes that perhaps they asked the wrong questions. The studies that are viewed as more useful had the following characteristics:

a. the researchers assessed educational outcomes over time, instead of examining short term gains
b. the researchers developed case studies of individual's thinking processes
c. the researchers relied on teacher judgments as an important source of evidence, combined with information from other sources.

. . . any research study, experimental or otherwise, begins with subjective judgments about the importance (or worth) of the questions being asked, the ways in which evidence is collected, the meaning of the tools or instruments being used, and the choice of analytical strategies. (p. 233)

Cost effectiveness and educational technology

Another important consideration in a realistic framework for educational technology (and related research) is the issue of cost effectiveness. Clearly this issue should not be separated from other considerations. It may be quite appropriate to try out new and expensive technologies in a research environment as long as the costs and benefits are included in the final report which can then serve as a guideline to future implementation projects. It is somewhat surprising to find that although decision-makers urgently need information about the cost-effectiveness of new technologies, there is little literature available on this topic.

Moonen (1990) prepared a report for ETC which summarizes some of the literature on the cost-effectiveness of educational technology. He states "available literature deals mostly with the cost aspect, although the effectiveness aspect is very often mentioned in the title of articles" (p. 3). Since educational expectations or goals are often not very explicit, it becomes difficult to know whether or not an implementation of technology meets those goals in a cost-effective manner. It is not even easy to really measure the true cost of the implementation. There are usually hidden costs, and prices can be very unstable.

Moonen formulates a ratio using specific measures of effectiveness (relating to educational goals achieved) including:

- *number of students who complete a program*
- *number of potential dropouts who graduate*
- *number of graduates placed in appropriate jobs*
- *test scores (using appropriate instruments)*
- *student assessments of a program.*

These measures can be related to the impact of a new technology whose cost is known. They are quantifiable measures of educational goals. Moonen's conclusion is that "We should start specifying what we want in terms of costs and effectiveness measurements. The model developed above is a first step to support our expectations. From that perspective many research projects can be defined" (p. 30). Technological, or any other type of 'solutions' need to be compared to alternatives that might achieve the same goals for less cost, but this cannot happen if the goals have not been identified first.

Van Horn (1991) describes the 'student productivity argument' as follows: information technology must be used directly with the learners and not directed to the teachers. "We must concentrate on the 25 instead of the one. When we invest in new technology, we must invest in new learning systems, not in new teaching systems" (p. 528). This is based on the premise that although students do not receive a salary, and have therefore often been omitted as a cost element in the evaluation of school productivity, they represent a real cost to society that will increase if their learning environment becomes less effective in meeting their needs. Here, as in Moonen's framework, productivity cannot be evaluated outside of the context of well-defined educational expectations and goals.

The computer-mediated communications and information technology environments are neither cheap nor easy to implement. Bork (1990) describes the current situation:

> *. . . although there would seem to be some interesting possibilities for pedagogical developments that could take place in network environments, and could not take place in other environments, these possibilities have scarcely been touched. So networks become an expensive addition, not contributing much to the learning situation. But, like many of the early stages in the history, they reflect a potential that might be realized if the final stage of history is ever attained. (p. 103)*

Research and evaluation methods that might apply to SITP

The following sections give a sample of studies that relate to technological applications from non-educational as well as educational environments. They have been selected because they incorporate research methods that might be useful to SITP.

Methodologies used outside of the school-based educational environment

Diverse experimental and observational methods have been used to evaluate issues related to computer use in the workplace. The goals of such research may not exactly match those of education, but some of the methodology might be suitable (with modifications) for finding out more about educational applications and some of the results might well be generalizable to the educational context. This section of the paper touches on a few studies (mostly related to the improvement of human-computer interfaces or to the issue of improving human performance through computer use) that seem to be of interest.

Cook and Ridley (1990) looked at librarians using the CoSy computer conferencing system at McMaster University. Their main tools of investigation were a survey and an analysis of conference use. They state that "in communications research, it is often difficult to isolate the effects of the system, the environment, the participants and other communications methods available. Much CMCS [computer mediated communications systems] research, as with this study, is done many months after the introduction of a new system" (p. 413). A conclusion of this study is that successful CMC requires task orientation, support from administrators, and easy access.

As with many similar studies, Cook and Ridley observed and analyzed patterns of system usage. User difficulties were noted and steps to overcome them (such as ensuring greater access to computers) were suggested. Beneficial results are assumed to be an outcome accompanying increased usage of the system, but such results are not described nor measured or observed in the study. A section of the paper, entitled 'usefulness of CMCS' describes the ten survey categories of useful aspects of the system, and ranks them based on survey results. Respondents rated the system as useful for exchanging information and asking questions, but does not indicate whether this is an improvement over the previous methods used for similar purposes. In fact, the conclusion is that the librarians joined out of curiousity, but their "continued use of the system would depend on direct application to their jobs or tasks" (p. 415).

Cherry (1990) discusses the strengths and weaknesses of methods such as surveys, lab studies and field studies to gain an understanding of database users. Surveys are economical and can sometimes be quite accurate but they usually lack depth and "provide only secondary data - what users say they do. This is based on their recollection of what they did, which is often inaccurate or not sufficiently detailed" (p. 20). In lab studies, the investigator has control and can be "confident that the observed effect . . . is actually due to the treatment, however, the artificial nature of laboratory settings threatens the external validity of these studies" (pp. 20-1). Field studies involve observation of real users in real environments. They are more expensive and are less easily controlled by the investigator, but provide ecologically valid results.

Software monitoring is a type of field study, but unless it is carefully planned and analyzed, it can provide a large volume of data that does not answer any meaningful questions. The conclusion is that methods are complementary, and should be used to support each other.

Another description of methodologies (which could be used in field studies in the educational environments) is presented by Graesser, Gordon, Forsythe, and Greer (1991). This paper describes the collection of information about the effectiveness of computer interfaces through verbal protocols, including on-line think aloud, retrospective memory, and question-probe methods. Verbal protocols involve a person describing their actions (or answering questions) as they perform a task or immediately afterwards.

> *One of the major virtues of verbal protocols is that they permit researchers to discover what cognitive structures and strategies humans use in tasks when the researchers have no theories to guide their expectations; that is, verbal protocol methods are excellent in the discovery phase of research. (p. 16)*

However, since the verbal protocol situation is not typical of normal performance (people don't usually talk out loud while performing a task), it is necessary to validate conclusions derived from observations made during the verbal protocol process; for instance, expectations from verbal protocols can be evaluated by how well they predict performance in normal situations.

An example of a study using a think-aloud methodology is a library search study conducted by Ingwersen (1984). During the task of an information search, librarians were asked to describe what they were doing, and why. An analysis of the librarians' records allowed the researcher to relate various searching behaviours to the models of information held by individual librarians. The results have been successfully used to teach reference librarianship.

O'Shaughnessy, Coskuntuna, and Kantro (1987) devised controlled experiments to investigate the human decision-making process when using an on-line information retrieval system. Participants were required to evaluate information about products, and make a purchasing decision. The conclusion for users of on-line systems here is that the human information-processing capacity is limited, and systems must be designed to alleviate these limitations by structuring access to information.

Streitz (1987) has said the following about the state of human-computer interaction research:

> *Most of the current research is concerned with evaluating existing systems . . . it is not very innovative. A second strategy is to be part of a rapid prototyping team thus allowing to be very close to new technological developments . . . but . . . it is necessary to complement these approaches by trying to progress conceptually one step ahead of existing technology . . . and provide frameworks for future interactive systems. The possible role of psychologists or cognitive ergonomists would then be to propose requirements which then have to be met by technology. (p. 77)*

Bamber (1990) reviews Zuboff's 1988 book entitled *In the Age of the Smart Machine: The Future of Work and Power*, which takes an industrial anthropological approach to studying technology use in the work place. The focus question, does technology rob people or empower people? is dealt with through a variety of research methods, including getting people to draw pictures of their experiences with new computer systems. Observation of meetings, small group discussions and analysis of products were other approaches used in this investigation. The conclusion is that the impact of technology could go in either direction. People may become empowered or they may become enslaved–it is an organizational choice. The caution is that the more expedient approach (easier implementation, less radical reorganization of power hierarchies) is also the less humanistic choice.

Education-oriented methodologies
This section presents examples of two general types of methodologies, along with examples of how they can be combined to form a hybrid, all from educational technology research. The first examples (Archer, 1989, and Reynolds & Hart, 1989) are controlled, experimental studies. Also taking the experimental perspective is the report for the U.S. Department of Education conducted by Becker. The hybrid (Newman, 1990) involves a method that controls the outcome and observes the processes used to achieve that outcome. Three other examples involve studies or approaches that can be categorized as naturalistic (Neuman, 1989, Baird & Mitchell, 1986, Lytle & Cochran-Smith, 1990).

Archer (1989) conducted a study of the problem-solving, idea generating, and decision-making abilities of MBA students in computer conference groups of varying sizes. The groups were carefully matched for previous computer experience and all participants received the same training. Each group analyzed the same business "mini-case" through the conference, and the quality of their analyses was compared. Similar studies conducted in face-to-face group meetings indicated that problems (such as unequal participation) arise for a group size greater than five members. The conferencing methodology used was seen to alleviate this problem, and comparable work was generated in groups of as many as 13 students or as few as four.

Reynolds and Hart (1989) designed an experiment where children's stories (composed using a word processor) were evaluated before and after various writing procedures were taught. Matched groups had either cognitive mapping strategies, brainstorming, or outlining explained to them. The effectiveness of the various procedures on writing and revision was examined.

Meta-analysis is the process of combining the results of a series of studies conducted in a particular area. Becker (1986) described the inadequacy of the majority of individual studies in the area of instructional computer use: studies based on survey methods lacked validity, classroom studies or field experiments rarely used random assignment techniques and were usually conducted over very short time periods with groups too small to provide meaningful results. Because meta-analysis (as it is usually conducted) incorporates studies with such defects, Becker (1987) used a similar, but more refined, technique called 'best-evidence synthesis' and concluded that "the existing evidence of computer effectiveness is very scanty" (p. 24). He proposes a large-scale, randomized and experimentally controlled series of studies to be conducted over a period of three years. This study will use field research and survey techniques and will focus on the effect of a variety of types of computer use in specific curriculum areas.

Newman (1990) describes studying the organization of computers in schools (in this case the environment was classrooms with LANs) through a research methodology called the "formative experiment." In the formative experiment, pedagogical goals are set and the process required to achieve those goals is observed.

> *Instead of rigidly controlling the treatments and observing differences in the outcome, as in a conventional experiment, formative experiments aim at a particular outcome and observe the process by which the goal is achieved . . . if the environment, rather than the technology, is the unit of analysis, changes in the instructional interactions, changes in teacher roles, and other ways that the educational environment is changed are observed . . . the changes in organization brought on by technological support can be understood also as changes in the support for cognition. (p. 10).*

Neuman (1989) discusses the potential of a naturalistic inquiry paradigm in the development of computer-based instruction:

> *Three areas contribute to making the naturalistic, or qualitative approach the most promising alternative for gaining the detailed, conte:·· bound information required to design maximally effective courseware: the theoretical assumptions underlying the naturalistic paradigm, the methodology commonly associated with it, and the nature of the findings that result from naturalistic studies. (p. 40)*

The theoretical assumptions emphasize the importance of context in learning, and are based on cognitive theories. The methodology includes "prolonged and persistent observation of students and teachers using courseware and engaging in introductory and follow-up activities" (p. 44). The nature of the findings "could provide the foundation for a wide array of design principles upon which courseware developers could draw to enhance the quality and effectiveness of courseware used in schools" (p. 49).

The above approaches, varying in their degree of experimental control, are alike in that the researcher is external to the actual learning environment. A different approach, usually incorporating naturalistic methodologies, involves the teacher as the individual who designs and conducts the research. The remaining examples describe projects where teachers take an active role in research.

Action research, used in the Australian Project of Enhancing Effective Learning, or PEEL (Baird & Mitchell, 1986) is a naturalistic methodology that engages the teacher as research designer and principal investigator, within a classroom of students who are also actively involved in investigating their own learning. Research of this type is not an 'add-on' to a particular program, but becomes an integral part of the teaching and learning environment. PEEL involves a framework for teachers and learners to examine and revise their everyday processes. By providing a set of assertions about teaching and learning, and activities such as journal writing and concept mapping, this methodology encourages the change from rote-learning to knowledge creation.

The teacher as researcher has also been defined by Lytle and Cochran-Smith (1990) as the "systematic, intentional inquiry by teachers about their own school and classroom work" (p. 84). Through journals, essays, oral inquiry, and classroom studies, teachers can add to the knowledge base of their profession. Although there has been some debate about the status and objectivity of this type of research, these authors argue that the power of such work lies in the continuous revision of questions and methods and the on-going analysis of information. Perhaps the most important benefit is that teachers involved in research projects become more aware of educational issues, and begin to think more critically about the learning environment.

Summary of research and evaluation issues

It is clear educational technology research and evaluation exists in many forms and employs many methodologies. Research questions should be based on a theoretical framework that incorporates a definition of relevant educational expectations. Methods are being devised which incorporate the objectivity of experimental studies and the contextual validity of field studies. Perhaps the results of research employing such methods will influence educational practice in a way that has not occurred to this point.

Conclusion

The intention of this paper has been to provide a background perspective, based on a sampling of current literature, for the research and evaluation component of SITP. Although a wide range of literature has been covered, there are probably some important studies and perhaps a few points of view that have not been included in this review.

It is interesting to note that the work of preparing such a review incorporates many of the activities that will be performed by students as part of the project: gathering information from many sources (including database searches), evaluating that information for its value in addressing a particular problem (how to design a research agenda for SITP), and finally, using (in this case, summarizing and synthesizing) that information to create a format that could be useful to a particular audience.

A large scale networking project, such as SITP, offers students access to information that would not be possible otherwise. It also provides an opportunity to observe how learning takes place in an information-rich environment. The premise of this paper has been that in order to evaluate new educational directions, there must first be a consideration of the potential relationship between the new directions and the expectations, goals, and purpose of education. I believe that this requires an understanding of how learning takes place and a clarification of what we expect children to learn and why we expect them to learn it. In British Columbia, the *Report of the Royal Commission on Education* and the *Year 2000* paper have addressed these issues. The current paper provides a perspective (derived from a literature review) about specific issues related to learning through technology. The particular issues addressed have been selected because they can provide a framework for formulating some of the many questions raised by the unique situation of SITP.

The literature on cognitive theory provides a useful perspective on learning. Literature that considers the society of the future, including the impact of new technologies, gives us a framework for deciding what will be important for our children as they move on in life. Perhaps a goal for all educational systems should be to develop and use theoretical frameworks that incorporate the 'what, why, and how' of learning. Such frameworks can assist in decision-making about all types of educational innovations, including new technologies.

The unnecessary division between theoretical and practical issues would be narrowed by a spirit of collaboration between researchers and practitioners; after all, both groups are working toward providing effective learning environments for students. Everyone involved in the processes of education (including students and parents) operates on the basis of theoretical frameworks about (or systems for understanding) educational issues. Communication is easier when the theoretical frameworks are made explicit.

This paper has included examples of various research methodologies to provide research design ideas for projects that investigate the impact of information technologies (such as telecommunications) on learning. As these technologies become more widely used in educational environments, it is important to evaluate their success in a way that is objective, useful and acceptable to educators.

The following is a very brief summary of important points from this paper:

- The cognitive perspective, which views learning as a complex interaction between the internal state of an individual and incoming information, is currently influential in a variety of areas. The same set of cognitive principles applies to traditional environments as well as those that are computer-based and/or information-rich. The most effective learning environments:
  - consider the learner's pre-existing mental models
  - provide cues (such as strategies) for the creation of new mental models
  - do not overtax the limitations of human attention
  - recognize the importance of context.

- Technology is having a major impact on our society and it is likely that technological familiarity (or lack thereof) will have profound impact on various groups and subgroups within our culture. We are becoming increasingly wealthy in 'information,' but it is not clear that this corresponds to an increase in our degree of understanding or meaningful use of that information. Educators must be aware of the impact of information technologies and structure clear rationales for their implementation.

- Educational technology research and evaluation must have a theoretical framework that incorporates what we know about learning as well as what we know about technology. The effectiveness of any educational innovation must be evaluated on the basis of its impact on learning (with learning expectations clearly defined) in relation to the associated costs (time, money, and other). Research methodologies in education have not always led to acceptable results.

Citations

Acker, S.R. (1990). When application leads theory: A design orientation for teaching and research in information technology. *Educational and Training Technology International, 27(3)*, 318-327.

Allan, J. (1991). Literacy at work. *Canadian Business*, February, pp. 70-73.

Anderson, J.S.A. (1991). Information technology - a cross-curricular competence for all pupils. *Computers and Education, 16(1)*, 23-27.

Archer, N.P. (1989). Improving idea generation during decision making in small group computer conferences. *Canadian Journal of Educational Communication, 18(2)*, 111-123.

Baird, J.R., & Mitchell, I.J. (1986). *Improving the quality of teaching and learning: An Australian case study - the PEEL project.* Melbourne: The Monash University Printery.

Bamber, G.J. (1990). Information technologies: To automate or to informate? *Prometheus, 8(2)*, 345-355.

Barker, J. & Tucker, R.N. (1990). *The Interactive Learning Revolution: Multimedia in Education and Training.* New York: Kogan Page.

B.C. Ministry of Education (1990). *Year 2000: A Framework For Learning.* Victoria, BC: Province of British Columbia.

Becker, H.J. (1987). *The impact of computer use on children's learning: What research has shown and what it has not.* Report No. 18, Center for Research on Elementary & Middle Schools, Baltimore MD: OERI.

Becker, H. J. (1986). The effects of computer use on children's learning: Limitations of past research and a working model for new research. *Peabody Journal of Education, 64(1)*, 81-110.

Belkin, N.J. (1990). The cognitive viewpoint in information science. *Journal of Information Science*, 16, 11-15.

Berryman, S.E. (1990). Sending clear signals to schools and labor markets. In J. L. Schwartz & K.A. Viator (Eds.), *The prices of secrecy: The social, intellectual, and psychological costs of current assessment practice*, (pp. 35-46). Harvard Graduate School of Education: Educational Technology Center.

Bork, A. (1990). A historical survey of computer technology in education. In B. Branyan-Broadbent & R.K. Wood (Eds.), *Educational Media and Technology Yearbook, 1990*, (pp. 91-105). Englewood, CO: Libraries Unlimited, Inc.

Bosco, J. (1988). Introduction. *Peabody Journal of Education, 64(1)*, 1-4.

Boyd, G. (1990). Appropriate uses of computer-mediated communication systems for education: Conferencing 'R-PLACES'. *Educational & Training Technology International, 27(3)*, 271-275.

Bransford, J.D., Goin, L.I., Hasselbring, T.S., Kinzer, C.Z., Sherwood, R.D., & Williams, S.M. (1988). Learning with technology: Theoretical and empirical perspectives. *Peabody Journal of Education, 64(1)*, 5-26.

Brown, J.S. (1989). *Situated learning - From street smarts to expertise.* Paper presented at the Smithsonian Resident Associates; Program

Seminar on How We Think and Learn.

Brown, J.S. (1985). Process versus product: A perspective on tools for communal and informal electronic learning. *Journal of Educational Computing Research, 1(2)*, 179-201.

Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18(1)*, 32-41.

Brown, J.S., Collins, A., & Duguid, P. (1988). *Situated cognition and the culture of learning.* Institute for Research on learning Report No. IRL 88-0008, 1-32.

Chaiklin, S.A., Hedegaard, M., Navarro, K., & Pedraza, P. (1990). The horse before the cart: A theory based approach to using computers in education. *Theory Into Practice*, XXIX(4), 271-275.

Cherry, J. (1990). Methods of studying database users: The role of surveys, laboratory studies and field studies. *The Canadian Journal of Information Science, 15(2)*, 17-29.

Chesebro, J., & Bonsall, D. (1989). *Computer-Mediated Communication: Human Relationships in a Computerized World.* The University of Alabama Press, Tuscaloosa, Alabama.

Clarkson, M.A. (1991). An easier interface. *Byte*, February, 277-282.

Cook, D., & Ridley, M. (1990). Computer-mediated communications systems: Will they catch on? *CLJ*, December, 413-417.

Cuban, L. (1984). *How Teachers Taught: Constancy and Change in American Classrooms, 1890-1980.* New York: Longman.

Dede, C. (1989). The evolution of information technology: Implications for curriculum. *Educational Leadership, 47(1)*, 23-26.

Dede, C. (1987). Empowering environments, hypermedia and microworlds. *Computing Teacher, 15(3)*, 20-24.

DiSessa, A.A. (1987). The third revolution in computers and education. *Journal of Research in Science Teaching*, 24(4), 343-367.

DiSessa, A.A. (1988). What will it mean to be "educated" in 2020. In R.S. Nickerson and P.P. Zodhiates (Eds) *Technology in Education: Looking toward 2020.* Hillsdale NJ: Lawrence Erlbaum Associates, 43-66.

Edwards, D.M., & Hardman, L. (1989). 'Lost in hyperspace': Cognitive mapping and navigation in a hypertext environment. In R. McAlees (Ed.) *Hypertext: Theory into practice.* Norwood, NJ: Ablex Publishing Corporation.

Emihovich, C. (1990). Technocentrism revisited: computer literacy as cultural capital. *Theory into Practice, XXIX(4)*, 226-234.

Ford, N. (1990). Book review. *Educational and Training Technology International, 27(3)*, 342-344.

Frye, D., Littman, D.C., & Soloway, E. (1988). The next wave of problems in ITS: Confronting the "user issues" of interface design and system evaluation. In Joseph Psotka, L. Dan Massey, & Sharon A. Mutter (Eds.) *Intelligent Tutoring Systems: Lessons Learned*, (pp. 451-478). Hillsdale, NJ: Lawrence Erlbaum Associates Publishers.

Gagne, R. & Briggs, L. (1979). *Principles of instructional design (2nd Edition).* New York: Holt, Rinehart and Winston.

Garner, R. (1990). When children and adults do not use learning strategies: Toward a theory of settings. *Review of Educational Research, 60(4)*, 517-529.

Goldberg, F.S. (1988). Telecommunications and the classroom: where we've been and where we should be going. *Computing Teacher, 15(8)*, 26-30.

Graesser, A.C., Gordon, S.E., Forsythe C., & Greer, J. (1991). Design of optimal person-artifact interfaces: Contributions from cognitive science. *Educational and Training Technology International, 28(1)*, 15-21.

Harasim, L. (1990). *Online education: Perspectives on a new environment.* New York: Praeger.

Hildreth, C.R. (1989). *Intelligent interfaces and* *retrieval methods for subject searching in bibliographic retrieval systems*. Library of Congress, Washington, D.C.

Hirsch, E.D. (1987). *Cultural literacy: what every American needs to know*. Boston, MA. Houghton-Mifflin.

Ingwersen, P. (1984). A cognitive view of three selected online search facilities. *Online Review(8)*, 465-492.

ISTE (1989). *Telecommunications in the Classroom*. Eugene, OR: Computer Learning Foundation and Palo Alto, CA: International Society for Technology in Education.

Jonassen, D., & Wang, S. (1990). Hypertext, learning and instructional design. In Branyan-Broadbent, B., & Wood, R.K., (Eds.) *Educational Media and Technology Yearbook*, (pp. 156-169). Englewood, CO: Libraries Unlimited Inc.

Kozma, R.B. (1987). The implications of cognitive psychology for computer-based learning tools. *Educational Technology*, November, 20-25.

Kurshan, B. (1990). Educational telecommunications connections for the classroom - part 2. *The Computing Teacher, 17(7)*, 51-52.

Lake, D. (1989-90). Two projects that worked: Using telecommunications are a resource in the classroom. *The Computing Teacher, Third Annual Conference Issue*, 21-23.

Lehrer, R. (1989). Computer-assisted strategic instruction in McCormick, Miller, Pressley, Eds, *Cognitive Strategy Research: From Basic Research to Educational Applications*, (pp. 303-320). New York: Springer-Verlag Inc.

Lewis, C.H. (1990). A research agenda for the nineties in human-computer interaction. *Human-computer Interaction*, 5, 125-143.

Litchfield, R. (1991). Solving an education crisis. *Canadian Business*, February, 57-73.

Lytle, S.L., Cochran-Smith, M. (1990). Learning from teacher research: A working typology. *Teachers College Record, 92(1)*, 83-103.

Mason, R. (1989). An evaluation of CoSy in an open university course. In R. Mason & A.R. Kaye (Eds.), *Mindweave: Communication, computers and distance education* (pp. 115-145). Oxford: Pergamon Press.

Mason, R. (1988). Computer conferencing: A contribution to self-directed learning. *British Journal of Educational Technology, 19(1)*, 28-41.

Maule, R.W. (1990). A review of current research in hypermedia information design. *Hypernexus: Journal of Hypermedia and Multimedia Studies, 1(2)*, 6-8.

McClintock, R.O. (1988). Marking the Second Frontier. *Teachers College Record, 89(3)*, 345-351.

McCormick, C.B., Miller, G.E., & Pressley, M. (Eds.), *Cognitive Strategy Research: From Basic Research to Educational Applications*. New York: Springer-Verlag Inc.

McCoy, L.P. (1989-90). Computer programming can develop problem solving skills. *The Computing Teacher, 17(4)*, 46-49.

Merrill, M.D., Li, Z., & Jones, M.K. (1990). ID2 and constructivist theory. *Educational Technology*, December, 52-55.

Moonen, J. (1990). *Cost, effectiveness, and expectations: concepts and issues with respect to educational technology*. Report submitted to the Educational Technology Centre of British Columbia.

More, E. (1990). Information systems: People issues. *Journal of Information Science*, 16, 311-320.

Muckler, F.A. (1987). The human-computer interface: The past 35 years and the next 35 years. In G. Salvendy, (Ed.) *Cognitive Engineering in the Design of Human-Computer Interaction and Expert Systems*, (pp. 3-12). Amsterdam: Elsevier Science Publishers.

Neuman, D. (1988). Naturalistic inquiry and computer-based instruction: rationale, procedures and potential. *ETR&D, 37(3)*, 39-51.

Newman, D. (1990). Opportunities for research on the organization impact of school computers. *Educational Researcher*, April, 8-13.

Newman, D., Griffin, P., & Cole, M. (1989). *The Construction Zone: Working for cognitive change in school*. Cambridge: Cambridge University Press.

Nickerson, R.S. (1988). Technology in education in 2020: Thinking about the not-distant future. In R.S. Nickerson and P.P. Zodhiates (Eds.), *Technology in Education: Looking toward 2020*, (pp. 1-10). Hillsdale NJ: Lawrence Erlbaum Associates.

Nipper, S. (1989). Third generation distance learning and computer conferencing. In R. Mason & A.R. Kaye (Eds.), *Mindweave: Communication, computers and distance education* (pp. 63-73). Oxford: Pergamon Press.

North, R. (1991). Managing the integration of information technology across the curriculum of the secondary school. *Computers and Education, 16(1)*, 13-16.

O'Shaughnessy, M.P., Coskuntuna, S., Kantro, E. (1987). Multiple attribute decision making and on-line information systems. In G. Salvendy, (Ed.) *Cognitive Engineering in the Design of Human-Computer Interaction and Expert Systems*, (pp. 61-66). Amsterdam: Elsevier Science Publishers.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.

Paris, S.G. (1988). Models and metaphors of learning strategies. In C.E. Weinstein, E.T. Goetz, & P.A. Alexander (Eds.), *Learning and study strategies: Issues in assessment, instruction, and evaluation* (pp. 299-321). San Diego: Academic.

Pea, R.D., & Soloway, E. (1987). Mechanisms for facilitating a vital and dynamic education system: Fundamental roles for education science and technology. In B. Branyan-Broadbent & R.K. Wood (Eds.), *Educational Media and Technology Yearbook, 1990*, (pp. 31-90). Englewood, CO: Libraries Unlimited, Inc.

Perkins, D.N., & Salomon, G. (1988). Teaching for transfer. *Educational Leadership*, September, 22-32.

Perkins, D.N., & Salomon, G. (1989). Are cognitive skills context-bound? *Educational Researcher*, January-February, 16-25.

Pressley, M., Forrest-Pressley, D., Elliot-Faust, D.L., & Miller, G.E. (1985). Children's use of cognitive strategies, how to teach strategies, and what to do if they can't be taught. In M. Pressley & C.J. Brainerd (Eds.), *Cognitive learning and memory in children* (pp. 1-47). New York: Springer-Verlag.

Pressley, M., Goodchild, F., Fleet, J., Zajchowski, R., & Evans, E.D. (1989). The challenges of classroom strategy instruction. *Elementary School Journal*, 89, 301-342.

Relan, A. (1991). The desktop environment in computer-based instruction: cognitive foundations and implications for instructional design. *Educational Technology*, January, 7-14.

Report of the Royal Commission on Education (1988). Victoria, BC: Province of British Columbia.

Reynolds, S.B., & Hart, J. (1989). Cognitive mapping and word processing: Aids to story revision. *Journal of Experimental Education, 58(3)*, 273-279.

Rogers, A., Andres, Y., Jacks, M., & Clausen, T. (1990). Keys to successful telecomputing. *The Computing Teacher, 17(8)*, 25-28.

Romiszowski, A.J. (1990). Shifting paradigms in education and training: What is the connection with telecommunications? *Educational & Training Technology International, 27(3)*, 233-237.

Rothkopf, E.Z. (1988). Perspectives on study skills training in a realistic instructional economy. In C.E. Weinstein, E.T. Goetz, & P.A. Alexander (Eds.), *Learning and study strategies: Issues in assessment, instruction, and evaluation*, (pp. 275-286). San Diego: Academic.

Rosson, B., & Alpert, S. (1990). The cognitive consequences of object-oriented design. *Human-computer Interaction*, 5, 345-379.

Salomon, G. (1989). Book Review. Computing and Education: The Second Frontier (Special

Issue, 1988) edited by Robert O McClintock. *Journal of Educational Computing Research, 5(2),* 248-252.

Scardamalia, M., Bereiter, C. (1989). Schools as knowledge-building communities. In S. Strauss (Ed.) Vol. 5 *Human Development*. Norwood, NJ: Ablex.

Sless, D. (1985). Communication and the limits of knowledge. *Prometheus, 3(1),* 111-118.

Smaldino, S., & Thompson, C. (1990). Infusion of science software: Applying Gagne's strategies. *Journal of Computers in Mathematics and Science Teaching, 9(3),* 17-22.

Somekh, B. (1989). The human interface: Hidden issues in CMC affecting use in schools. In R. Mason & A.R. Kaye (Eds.), *Mindweave: Communication, computers and distance education* (pp. 242-246). Oxford: Pergamon Press.

Streitz, N.A. (1987). Cognitive compatibility as a central issue in human-computer interaction: Theoretical framework and empirical findings. In G. Salvendy, (Ed.) *Cognitive Engineering in the Design of Human-Computer Interaction and Expert Systems,* (pp. 75-82). Amsterdam: Elsevier Science Publishers.

Symons, S., Snyder, B., Cariglia-Bull, T., & Pressley, M. (1989). Why be so optimistic about cognitive strategy instruction? In C.B. McCormick, G.E. Miller, & M. Pressley (Eds.), *Cognitive Strategy Research: From Basic Research to Educational Applications,* (pp. 1-32). New York: Springer-Verlag Inc.

Teles, L. (1991). The use of audio and computer conferencing to support situated learning: The case of the telelink consortium. *Proceedings of the 24th Annual Hawaii International Conference on System Sciences,* January, 1991, (372-378).

Thompson, D. P. (1990). Network capabilities and academic realities: Implementing interactive networking in a community college environment. *Journal of Computer-Based Instruction,17(1),* 17-22.

Tiffin, J. (1990). Telecommunications and the trade in teaching. *Educational and Training Technology International, 27(3),* 240-243.

Tucker, R.N. (1989). *Interactive media: The human issues*. London: Kogan Page.

USWest (1989). *Planning for telecommunications: A school leader's primer.* Portland OR: U S West Communications.

Van Horn, R. (1991). Educational power tools: New instructional delivery systems. *Phi Delta Kappan,* March, 527-533.

Van Weering, B., & Plomp, T. (1991). Information literacy in secondary education in the Netherlands: The new curriculum. *Computers in Education,* 16(1), 17-21.

Waugh, M.L., & Levin, J.A. (1989). Telescience activities: Educational uses of electronic networks. *Journal of Computers in Mathematics and Science Teaching,* 8(2), 29-33.

Williges, B. (1987). Analyzing human-computer dialogue interfaces. In G. Salvendy, (Ed.) *Cognitive Engineering in the Design of Human-Computer Interaction and Expert Systems,* (pp. 67-74). Amsterdam: Elsevier Science Publishers.

Winne, P. (in press). State-of-the-art instructional computing systems that afford instruction and bootstrap research. To appear in: Jones, M. and Winne, P.H. (Eds.). *Foundations and Frontiers of Instructional Computing Systems.* Berlin: Springer-Verlag.

Winne, P. (1985). Steps toward promoting cognitive achievements. *The Elementary School Journal, 85(5),* 673-693.

Yurkovich, S.P. (1989). Using computer telecommunications to improve earth-science education at middle and secondary schools. *Journal of Geological Education, 37(5),* 314-316.

Ziedenberg, J. (1991). Extra Curricular. *...an Business,* pp. 66-69.

Zuboff, S. (1988). *In the Age of the Smart Machine: The future of work and power.* New York: Basic Books.

Other Readings

Atkins-Simon, K., & Schrum, L. (1990). *Beyond electronic penpals: The next step towards the virtual classroom*. Paper presented at the Third Symposium on Computer Mediated Communication, University of Guelph, May, 1990.

Becker, H.J. (1987). The importance of a methodology that maximizes falsifiability: Its applicability to research about Logo. *Educational Researcher, 16(5)*, 11-16.

Belkin, N. J. (1987). First Toronto conference on database users; studies of user needs and behaviour. *Canadian Journal of Information Science, 12(3-4)*, 31-79.

Belkin, N. J. (1987). Distributed expert-based information systems: An interdisciplinary approach. *Information Processing and Management, 23(5)*, 395-409.

Bliss, J., & Ogburn, J. (1989). Tools for exploratory learning. *Journal of Computer Assisted Learning, 5*, 37-50.

Branyon-Broadbent, B. & Wood, R.K. (1990). *Educational Media and Technology Yearbook, 1990*. Englewood, CO: Libraries Unlimited, Inc.

Gould, J.D., Boies, S. J., & Lewis, C. (1991). Making usable, useful, productivity-enhancing computer applications. *Communications of the ACM, 34(1)*, 74-85.

Bugliarello, G. (1988). Toward hyperintelligence. *Knowledge: Creation. Diffusion, Utilization, 10(1)*, 67-89.

Butterfield, E.C. & Nelson, G.D. (1988). Theory and practice of teaching for transfer. *ETR&D, 37(3)*, 5-38.

Carland, J.C., Carland, J.W. (1990). Cognitive styles and the education of computer information systems students. *Journal of Research on Computing in Education, 23(1)*, 114-126.

Conklin, J., & Begeman, M.L. (1989). gIBIS: A tool for all reasons *Journal of the American Society for Information Science, 40(3)*, 200-213.

Costanzo, W.V. (1989) *The Electronic Text: Learning to Read, Write and Reason with Computers*. Englewood Cliffs, NJ: Educational Technology Publications.

Dede, C. (1990). What will the future hold for schools and technology. *School Administrator Special Issue: Computer Technology Report*, 39-40.

Dede, C. (1986). The implications of emerging technologies for the value-oriented curriculum. *Momentum*, 173, 42-44.

DeLoughry, T.J. (1989). Professors are urged to devise strategies to help students deal with 'information explosion' spurred by technology. *Chronicle of Higher Education*, 35.

Frese, M., Ulich, E., Dzida, W. (Eds.) (1987). *Psychological Issues of Human-Computer Interaction in the Work Place*. North-Holland, Amsterdam.

Hardman, L. (1989). Evaluating the usability of the Glasgow online hypertext. *Hypermedia*, 1(1), 34-63.

Held, C., Newsom, J., & Peiffer, M. (1991). The integrated technology classroom: An experiment in restructuring elementary school instruction. *The Computing Teacher*, March, 21-23.

Heller, R.S. (1990). The role of hypermedia in education: A look at the research issues. *Journal of Research on Computing in Education, 22(4)*, 431-442.

Hiltz, S. R. (1988). Productivity enhancement from computer-mediated communication: A system contingency approach. *ACM*, 31, 1438-1454.

Hiltz, S. R. (1989). *Correlates of learning in a virtual classroom*. Research Report No. CIS-89-22. Newark, N.J.: New Jersey Institute of Technology.

Jones, B.F. & Idol, L., (Eds.), (1991). *Dimensions of thinking and cognitive instruction*. Hillsdale, NJ: Erlbaum.

Kranch, D.A. (1989). The development and impact of a global information system. *Information Technology and Libraries ,8(4)*, 384-392.

Lehtonen, J. (1988). The information society and the new competence. *American Behavioral Scientist*, 32, 104-111.

Levin, H. & Meister, G. (1986). Is CAI cost-effective? *Phi Delta Kappan*, June, 1986, 745-749.

Levin, J., Waugh, M., & Kim, H. (1990). *Learning in electronic networks: global and local activity cycles*. Paper presented at the Boston meeting of the American Educational Research Association.

Levin, J.A., Rogers, A. Waugh, M. & Smith, K. (1989). Electronic networks: Appropriate activities for learning. *The Computing Teacher, 16(8)*, 17-21.

Locatis, C. (1989). Information retrieval systems and learning *Performance Improvement Quarterly* 2 3 4-15.

Long, J. & Whitefield, A. (1989). *Cognitive Ergonomics and Human-computer Interactions*. Cambridge: University Press.

Lytle, S.L., & Cochran-Smith, M. (1989). Teacher research: Toward clarifying the concept. *National Writing Project Quarterly*, 11(2), 22-27.

Mackay J.M., Lamb, C.W., & Shipp, S. (1989). The benefits of using cases in the information systems course. *Interface, 11(4)*, 39-41.

Marchionini, G. (1988). Hypermedia and learning: Freedom and chaos. *Educational Technology*, November, 8-12.

Marlett, N. (1990). Empowerment through computer telecommunications. *Computers in Education*, February, p. 18.

McCormick, S. & Zutell, J. (Eds.) (1989). *Cognitive and Social Perspectives for literacy research and instruction*. Chicago, IL: National Reading Conference.

McLean, R.S. (1989). An educational infrastructure for microcomputers in Ontario. *Technological Horizons in Education*, 16(5), 79-82.

Nickerson, R.S. & Zodhiates, P.P. (1988). (Eds) *Technology in Education: Looking toward 2020*. Hillsdale NJ: Lawrence Erlbaum Associates.

Office of Technology Assessment (1988). *Power On!*, Washington, D.C., Congress of the United States.

Palvia, P. & Palvia, S. (1989-90). Key ergonomic characteristics of system development techniques. *Interface, 11(4)*, 86-91.

Psotka, J., Massey, L.D., Mutter, S.A., & Brown, J.S. (1988). *Intelligent Tutoring Systems: Lessons Learned*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Rawson, J.H. (1990). Simulation at a distance using computer conferencing. *Education & Training Technology International, 27(3)*, 284-292.

Richardson, V. (1990). Significant and worthwhile change in teaching practice. *Educational Researcher*, October, 10-18.

Riel, M. (1990). *Learning circles: A model for education telecomputing*. Paper presented at the Boston meeting of the American Educational Research Association.

Ritchie, J. (1990). Methods of studying users *The Canadian Journal of Information Science, 15(2)*, 30-37.

Romiszowski, A.J. (1990). Computer mediated communication and hypertext: The instructional use of two converging technologies. *Interactive Learning International, 6(1)*, 5-29.

Rosenberg, R. (1991). Debunking Computer Literacy. *Technology Review*, January, pp. 58-65.

Salisbury, D.F. (1990). Cognitive Psychology and its implications for designing drill and practice programs for computers. *Journal of Computer-based Instruction, 17(1)*, 23-30.

Salvendy, G. (1987). *Cognitive Engineering in the Design of Human-computer Interaction and Expert Systems*. Proceedings of the Second International Conference on Human-Computer Interaction, Honolulu, Hawaii.

Sankar, C.S. (1990). A framework to integrate applications, management and movement of information. *Information Management Review, 5(3)*, 55-67.

Scaife, M. (1989). Education, information technology and cognitive science. *Journal of Computer Assisted Learning, 5(2)*, 66-71.

Schuyten, G. (1987). The primary curriculum and new technology ways and means. *Education and Computing, 3(3)*, 125-131.

Scriven, M. (1986). Computers as energy: Rethinking their role in schools. *Peabody Journal of Education, 64(1)*, 27-51.

Smith, P.E. (1989). Some learning and instructional theory considerations for the development of computer related instructional materials. *Educational Technology*, November, 18-19.

The Cognition and Technology Group at Vanderbilt (1990). Anchored instruction and its relationship to situated cognition. *Educational Researcher*, August-September, 2-10.

Van Beek, J., Been, P., Hurts, K. (1989). Computer-based learning for on-line data base search. *Computers and Education, 13(4)*, 327-336.

Vandergrift, K.E. (1988). Hypermedia: Breaking the tyranny of the text. *School Library Journal 35(3)*, 30-35.

Weinberg, N. (1990). *Computers in the Information Society*. Boulder Colorado: Westview Press.