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Computers as cognitive media: examining the potential of computers in education

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Abstract

Despite a history of achieving only marginal benefits from using technology in education, many schools and other educational organizations are investing heavily in computer technology. This paper examines common criticisms of educational computer use, considers how society and schools have reacted to previous technological trends, and outlines relationships between diverse approaches to computer use and the ensuing outcomes that can be expected. Two approaches to media use, representational and generative, are described in an attempt to identify instructional approaches that improve educational quality. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The promise of educational benefits, anticipated since the early days of computer use, has accelerated with the increased availability of computers and the Internet in schools. Yet, the expanding use of computers proceeds without a clear vision for the level of effective and innovative use expected by the public, educators, and instructional technology researchers, and implied by the capabilities of the machines themselves (cf. US Congress, 1995). The benefits have, as a rule, failed to accrue.

Although the initial optimism may have been unrealistic, various criticisms have been raised about the wisdom of using computers in schools. Computers were predicted to improve both teaching and student achievement. Students were expected to learn more through computer use: test scores would rise, students would remember more and they would learn at a faster rate. Moreover, computer-assisted education would help students to be prepared to enter and compete in a modern, global

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workforce (Oppenheimer, 1997). Despite continued optimism, we now find criticisms and concerns being raised regularly. Principal among the complaints is the failure to find an improvement in learners' performance. Computers have not produced improvements in test scores (Clark, 1983, 1994)

Another concern about computers is the channeling of limited educational resources to pay for new computer systems. The widespread infusion of computers into schools has drawn resources away from other educational funding needs. Computers are expensive and their rapid application to educational venues already short on funds often forces reductions elsewhere. One commonly cited example is a decrease in arts classes due to the expense of adding computers (Oppenheimer, 1997). Students' comprehensive educational experiences are compromised in order to purchase computers.

A third concern addresses the quality of the educational experience provided through computers. Computer activities, no matter how convincing, remain representations of experience. Activities that are sometimes championed as exemplary uses of the computer, e.g. following scientific expeditions into a rainforest via the Internet, or using e-mail to communicate with students in foreign countries, are limited, virtual experiences for children who may lack a broad base of real experience. Similarly, students may observe a virtual exhibition rather than participating in the authentic activity of traveling to an art museum. The virtual experience is flat and electronic, only visual, two-dimensional and mediated. Students are removed from first-hand experience and miss the opportunity to see a painting with real paint or to experience art in the context of a gallery. The experiences exist only on screen (Healy, 1997).

Some suggest that computers may cognitively de-skill students by supplanting mental exercise through computer use (Salomon, Perkins & Globerson, 1991). The computer now routinely performs many activities once performed in students' minds; consequently, the skills previously developed and practised are lost. The computer often performs or eliminates tasks that require mental effort and attendant learning. In effect, the computer may make schoolwork too easy. Critics note that term papers can be assembled easily by cutting and pasting from existing documents. The mental rigor of researching, summarizing, and organizing in students' own minds is lost (Rothenberg, 1997).

Using computers extensively may have other unanticipated effects. A traditional educational system based on reading and writing fosters the development of a linear, logical thought process (Bailey, 1996), a process that is valued and integrated into the structure of our society. Computer use, however, coupled with a societal infatuation with fast-paced, non-linear media in general, develops a haphazard, hypertext-structured thought process (Birkerts, 1994).

Given these criticisms a number of fundamental questions must be raised: What is the value of computers in education? And, critically, what will be the impact of computers on education due to wide societal use outside the classroom? How will general computer use in society change the way we conceptualize education?

In this paper we will examine the potential impact of computers on education through historical and theoretical frameworks. One goal of the study of history,

where we begin, is to better understand current events and future trends. We examine how new technologies have led to dramatic changes in society. We are particularly interested in how computer use in society may change the way we conceptualize education. Next we study how educational media have been used in the past. We hope to avoid repeating previous misconceptions, and establish patterns for effective media use. We also consider theoretical frameworks for education as they guide computer use and propose that different orientations have implications for how computers will be used and the outcomes that can be expected. In particular, we distinguish between media use for communication and importantly, for thought. Finally, we address implications of these observations for educational computer use and instructional design.

Our examination assumes that humans use diverse symbol systems (e.g. words, images, sounds, and numbers) for two purposes: to encode information that signifies ideas and to support thinking. For example, most of us have the ability to think in words that succinctly represent complex ideas. These symbols may be ordered, combined and manipulated to generate new ideas.

Using symbol systems requires structure and organization, which are often described as syntax and grammar (Carpenter, 1972; Wendt, 1954). Externalizing symbol systems requires a medium to record or transmit the symbols. Media, from this perspective are the capabilities or affordances rather than the artifacts of the recording or transmission (Fig. 1). External use of symbols allows the broad sharing

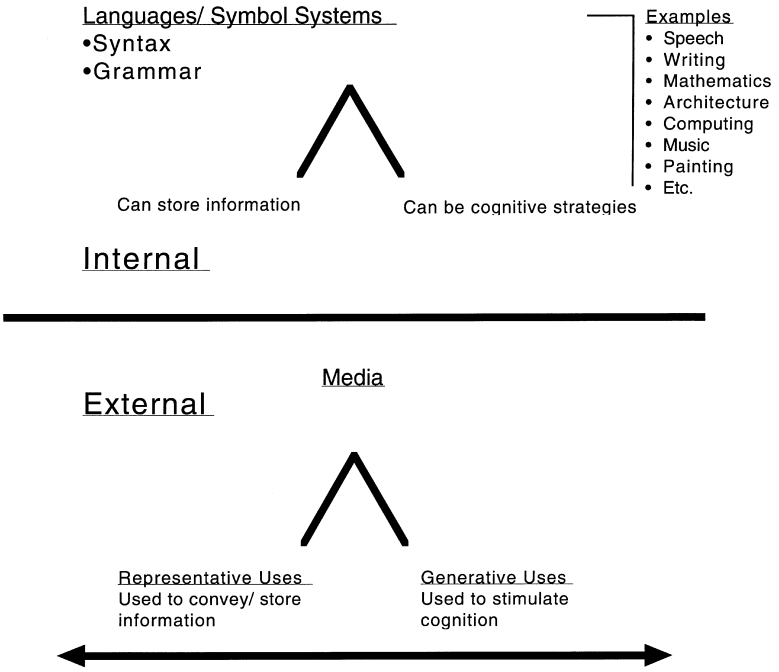

Fig. 1. Thinking represented in diverse languages/symbol systems.

of information, relief of scarce cognitive resources, and an iterative process of creation with the media.

Media are a diverse range of technologies and processes that humans use to explore, express or communicate ideas. As such, speaking, writing, painting, music, mathematics and other similar processes can be considered as examples of media, along with more traditional examples such as teaching machines, TV, and film strips.

2. The impact of media on society

History illustrates how changes in society's media capabilities profoundly affect the society itself (Innis, 1954). Postman (1992), summarizing Innis said, "New technologies alter the structure of our interests: the things we think *about*. They alter the character of our symbols: the things we think *with*. And they alter the nature of community: the arena in which thoughts develop" (p. 20).

Consider, for example, the changes achieved through the adoption of the alphabet and by mass printing of texts. Using the alphabet had a major impact on the way people organized knowledge and used their cognitive capabilities. This new medium, writing, was condemned by Plato as destructive of one's cognitive abilities (Norman, 1994; Postman, 1982); no longer did one need to rely solely on the knowledge in one's head. At the cognitive level the alphabet stimulated logical and analytical processes and changed the way people thought:

> We know that formal logic is the invention of Greek culture after it has interiorized the technology of alphabetic writing, and so made a permanent part of its noetic resources the kind of thinking that alphabetic writing made possible (Ong, 1982, p. 52).

At its simplest, written language became more accessible; more people were able to read and write a language codified with a simplified system of symbols than one composed of pictographs or ideograms (Logan, 1995; Ong, 1982). Logic replaced myth and a culture was enabled that developed the western bases for science, philosophy, history, and individualism (McLuhan & Logan, 1977).

The introduction of mass printing also had a major effect on society and education. Gutenberg and other printers using movable type stimulated the printing of large volumes of books that broadened western civilization. The availability of the printed word redistributed written literacy from the learned few to the masses. Reading and writing increased the amount of knowledge in existence; this intellectual development was not stimulated by differences in the capability of language, but by the ability to distribute texts broadly and efficiently. Humans' cognitive capability was increased by the efficient and economic distribution of text.

How did this distribution of knowledge change society? Postman (1982) described Gutenberg's change, allowing all to read the Bible, as making each reader

responsible for his/her own interpretation of the word of God. With literacy and learning broadly distributed, belief and social organization changed extensively. What new thoughts and ideas developed? The Reformation, the Enlightenment, and the development of scientific method and community. Martin Luther, Thomas Jefferson, Descartes, and Isaac Newton are all progeny of the printing press, a mechanical process that substantially improved the efficiency of reproducing written texts.

Such dramatic increases in efficiency cause unforeseen and cumulative effects on society, leading to radical change often secondary to the original technological advance. Broad distribution and use of computers may have an impact similar to the use of mass printing. As with movable type of Gutenberg and Erasmus, the expansion of computing capability has allowed the integration of this new aid to cognition into society. People have integrated computers into their thought processes, into the way they work and think. "Technologies are not mere external aids but also interior transformations of consciousness..." (Ong, 1982, p. 82). Computing exists now as part of many peoples' cognitive strategies, helping create and develop new ideas. We test, we model, we try out, and we interactively simulate our conceptions through the use of computers. Business is rife with the use of hypothetical spreadsheet models for financial analysis. What will be the effect of this change upon education?

3. Media use in education

Media use in American education during the last century can be characterized as the application of existing instructional methods to the new technology with subsequent disappointing results. This trend parallels the evolution of media in society. Initially, new media are often used to replicate the functions of older media. Early uses rarely reflect the potential of the new media.

New media are often initially used to transmit existing messages (Carpenter, 1972; Innis, 1954; McLuhan, 1964). Photographs, for example, were first compared to paintings, mechanically recreating visual scenes (Meggs, 1992). The first movies transmitted plays from the stage without modification; theatrical techniques such as staging and extended speech or monologues were often used in early movies (Carpenter, 1972). As television replaced radio as a broadcast medium, much of the material was transferred whole cloth to the video broadcast (McLuhan, 1964). Only later does each medium develop its own language, its own grammar and syntax, and each has its own prejudices.

> All languages are mass media. The new mass media — film, radio, TV are new languages, their grammars as yet unknown. Each codifies reality differently; each conceals a unique metaphysics. Linguists tell us it's possible to say anything in any language if you use enough words or images, but there's rarely enough time; the natural course is for a culture to exploit its media bias. (Carpenter, 1972, p. 162)

Contemporary movies now use cinematic techniques that are better suited to film than to stage. For example, flashbacks are often used to communicate ideas and contextualize events.

Similarly, educators have transplanted existing instructional methods onto new technologies. Lectures presented in person were initially transported verbatim to radio, and then to television. The attributes of the radio were rarely used effectively.

> These first years of university broadcasting were generally ineffective because many a professor repeated his classroom lecture before the microphone without realizing that a good lecturer was not necessarily an effective broadcaster. (Saettler, 1990, p. 198)

Transmission of the lecture was intended to improve education; to some extent it provided wider access for some learners. However, it is questionable whether education was more effective. The "School of the Air" (radio broadcasts) and "Sunrise Semester" (an early broadcast television course) are precursors to contemporary ITV (Interactive Television); they are extensions of the large lecture hall and similarly non-interactive (Saettler, 1990). Such uses of technology employ a larger virtual 'room' to connect to a larger audience, but the educational method is still a lecture, primarily using audio to transmit information. Adding technology does not change the instruction qualitatively. Given such a history, it is not surprising that initial educational uses of computers would focus on replicating existing instructional method. One of the most elusive questions concerning educational computer use continues to be how computers might improve learning.

4. Research on computer use in education

Research on the effects of computers in education has suffered from inherently flawed research methodologies. Two common approaches to software evaluation have been identified: efficiency and media comparison studies (Hannafin, Hannafin, Hooper, Rieber & Kini, 1996). Efficiency studies attempt to identify how existing goals can be achieved at lower cost and, though important, are not our focus here. Media comparison studies compare the relative efficacy of computers with other media, or attempt to identify unique contributions of media toward a predefined goal. However, neither approach has provided much insight into the potential of computing in education.

In general, media comparison research found a lack of educational improvement (Cuban, 1986). Clark (1983, 1994) argued that the media can only be accurately compared through the use of the same instructional method. Clark evaluated, compared, and discounted a substantial number of research projects. He claimed that any instructional method could be presented with a variety of media and that efficiency is the sole valid reason for media selection; "...media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition." (Clark, 1983, p. 445).

This research approach varies the media and holds constant the instructional method. In doing so, the different capabilities or affordances of the media are often removed from experimental evaluation. Using such an approach to compare two different media only addresses elements that can be presented in both media, i.e. the lowest common denominator. For example, if auditory information were central to the topic, all media being compared must have audio capability (Cobb, 1997).

Much of Clark's orientation is directly related to instructional systems that employ behaviorist pedagogy. It is an approach "...dominated by behavioral theories of learning and instruction and by procedures for applying theory to practice that are based ultimately on the assumption that behavior is predictable." (Winn & Snyder, 1996, p. 136). Unfortunately, this approach does little to unleash the potential of the technology. The new medium is being used to deliver the old method.

5. Theoretical orientations of computer use

The manner in which educators use media (including computers) is guided by their theoretical understandings of education (Pea, 1993; Winn & Snyder, 1996). The major watershed in pedagogy over the past 50 years has been a shift between instructivism and constructivism; described sometimes as a change from teacher-centered to learner-centered education, or from a behaviorist approach to a constructivist approach. That change has affected the way we use computers and leads to the question; do we *teach* with computers or do students *learn* with computers?

Teacher-centered instruction dominated classrooms for much of the 20th century (Winn & Snyder, 1996). This orientation focuses on how teachers can partition and present content and instructional strategies in ways that help students to acquire knowledge. From this orientation, education can be made more efficient through changes in delivery systems (Innis, 1954; Logan, 1995). Media, including film, radio, television, and computers are used to *deliver* instruction.

In contrast, learner-centered instruction attempts to engage students in activities that support knowledge construction through media use, but which are not designed to control learning. In this model, learners use media to investigate and to think.

How media are used greatly affects their educational potential. One way to describe how media are employed is to describe their uses along a continuum from representative to generative uses. In the representative sense, media are used to transmit information. In the generative sense, media are used for knowledge construction (Fig. 1).

Media can be used in representative or generative forms. Samples are illustrated in Table 1, and further examples describe how two media, writing and painting, can be used in representative or generative forms.

The process of notetaking can be used to illustrate how a student can use writing (the medium) in a representational or a generative mode. The manner in which a student takes notes significantly affects the value of that activity (Wittrock, 1990). Performed as a representational activity, notetaking provides the student with an

Table 1
Outcomes from representative versus generative media use

Medium	Representative uses	Generative uses
Speech	Lecture classes	Seminar/discussion classes
Writing	Notetaking to record a lecture	Notetaking to restructure or synthesize
Mathematics	Using a calculator to solve repetitive problems	Solving complex real-life problems, e.g. word problems
Computing	Word processing, email	Computers as cognitive media/mindtools
Painting	Recreating an image	Examining ideas through paint, cf. Cubism
Music	Playing from sheet music	Improvising on the piano

opportunity to store information that can be reviewed at a later time. (Clearly a tape recorder would be more efficient.) However, if notetaking is simply a recording action, then little cognitive benefit will accrue. In contrast, generative notetaking involves transforming the original information, allowing the student to integrate new information with existing knowledge stored in long-term memory (Peper & Mayer, 1978).

Painting also can be examined as a representative or generative medium. Painting is often understood as a representative activity in which the artist recreates the world. But painting can also be generative when the medium is used to think and explore ideas, which is the essence of modern art.

The invention of photography in the 19th century caused a major conceptual shift in the understanding and value of painting as an art form. When photography made possible accurate and efficient visual representation of the world, the value of a painted representation was questioned (Meggs, 1992).

Painting as a generative activity remained vital in the exploration of the concepts and ideas of the 20th century. Cubism, for example, examines and expresses added dimensions on a flat surface, and the thought processes of the artist are enabled and limited by the medium. For example, the cubist painting, "Desmoiselles d'Avignon" (Picasso, 1907), explored the concepts of the space-time continuum. Here, the left side is inspired by primitive expressions of tribal masks seen by Picasso at the Musee Trocadero (Fig. 2). The right side, however, changes the grammar and syntax of the existing symbol system, and simultaneously views the same subjects from the front and the back. "Picasso had done for art in 1907 almost exactly what Einstein had done for physics in his 'Electrodynamics' paper of 1905" (Everdell, 1997, p. 249).

At approximately the same time that Picasso communicated and explored in paint, Einstein explored similar space-time concepts through different symbol systems. Einstein initially manipulated mental images rather than words or mathematics. His ideas were developed first internally and then translated into text.

> The words of the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined... From a psychological

Fig. 2. Picasso, Pablo, 1907. "Les Desmoiselles d'Avignon" oil on canvas (8′×7′8″). The Museum of Modern Art, New York. Acquired through the Lillie P. Bliss Bequest. Photograph c. 2000 The Museum of Modern Art, New York. © 2000 Estate of Pablo Picasso/Artists Rights Society (ARS), New York.

> viewpoint this combinatory play seems to be the essential feature in productive thought. ... The... elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously only in a secondary stage, when the mentioned associative play is sufficiently established and can be reproduced at will (Einstein, in Ghiselin, 1952, p. 43).

Gardner (1993) explains how Einstein's ability to use mental images flexibly (i.e. to examine and manipulate spatial relationships), enabled him to explore concepts in depth. Einstein's mental skills were such that he required no external media to

represent or manipulate ideas. He had sufficient cognitive ability to edit, store and revise images without support from external representation. Few have that level of ability to use complex symbol systems without mediation (i.e. external symbol systems). When used to perform generative tasks media vary in their capabilities; not all are equal in their capability to structure thought. Artists work in media that enable their creations. Painting, composing, and writing poetry are creative cognitive activities, and exist only as the media enable and encourage their development.

> If the meaning of Goethe's Faust, of Van Gogh's landscapes, or Bach's Art of the Fugue could be transmitted in discursive terms, their authors should and would not have bothered to write poems, paint or compose, but rather would have written scientific treatises. (Von Bertalanffy, 1965, p. 41)

Similarly, learners use diverse symbol systems to help construct mental representations based upon the capabilities of each medium and the nature of the internal mental representations the learner wishes to construct. Clark may have been correct in stating that no medium is unique in its ability to deliver a given message, but different media vary greatly in their ability to help diverse learners to construct mental representations (Salomon, 1979).

Different media (Eisner, 1997; Von Bertalanffy, 1965), different languages (Logan, 1995; Whorf, 1956), different symbol systems (Salomon, 1979) enable and promote different thoughts, ideas, and beliefs. The specific medium one chooses influences the nature of generative creation.

> ...the symbol systems that typify a medium are not mere envelopes into which unaltered messages are inserted. The symbol systems affect the content and give it distinctive form. Indeed, as a medium such as television develops, it not only moves farther away from its next of kin — film and radio — it even changes filmic messages when these are re transmitted through it. (Salomon, 1979, p. 23)

Writing, mathematics, scientific thought, music, and painting have each, in their own way, advanced the cognitive capabilities of humans. Extending that thesis to the computer, we are in the midst of a transformation of the capabilities and functions of the mind. Computing, the newest extension, gives humans the capability to address larger and more complex problems.

6. Using computers generatively

Extensions of the mind, i.e. languages and media such as writing or mathematics, are interactively used to address large and complex issues (Donald, 1991; Logan, 1995; Ong, 1982). Symbols are recorded, stored, manipulated, communicated, and combined through the use of languages and media.

Writing extended human capabilities through a single symbol system, i.e. text. The computer is different, possibly unique, in its ability to store, deliver, and help manipulate a variety of symbol systems. The computer affords the ability to present, and manipulate a variety of symbols, to work in a number of languages, visually, acoustically, textually, numerically. And, for the first time in human history, the speed of the computer makes the use of these symbol systems widely available or accessible.

> The protean nature of the computer is such that it can act like a machine or like a language to be shaped and exploited. It is a medium that can dynamically simulate the details of any other medium including media that cannot exist physically. It is not a tool, although it can act like many tools. It is the first meta-medium, and as such it has degrees of freedom for representation and expression never before encountered and as yet barely investigated (Kay, 1984).

The ability to work with this mental extension is akin to the common understanding of literacy, i.e. the ability to write. What is important about computer use is not being able to word process, or view a multimedia presentation, but the ability to interact with the computer in the manipulation and creation of knowledge through the rapid manipulation of various symbol systems. The value is not in more efficient representation but in improving the capability to generate thought.

Here we are close to a failure. Inappropriate use of mental assistance leads to a loss of cognitive capabilities, to "deskilling" (Salomon et al., 1991). If learning is short-circuited, made easier, through the use of computers, the residual effects will be diminished. Anecdotally, we recognize the loss of our arithmetic skills through the ubiquity of the hand calculator. The essence of print being 'hard' while television is 'easy' is that effective learning requires cognitive effort (Salomon, 1984). If education is to build cognitive strengths, computer use must demand that learners invest mental effort.

Learning involves stimulation of the mind to create, organize, structure, analyze and hypothesize. From this perspective, we begin to examine educational use of computing in a new light. We should compare the computer not to books, but to a blank sheet of paper, a notepad, an artist's canvas, or a blackboard. The computer may be a tool, but the act of computing itself is a medium for thought.

7. Computers as media

There remains a tendency to describe the role of the computer in education as "just another tool" (McCullough, 1998). We believe this view of educational computing to be limiting. Indeed, viewed as such, we may be destined to repeat failures experienced with other technologies, as described earlier in this manuscript. Describing computers as tools limits our vision to previously established goals.

Media such as computers are traditionally described and investigated as tools that help to complete specific, pre-ordained tasks such as the delivery or recording of information. Media can be used in a representational manner to present instruction to help learners achieve existing educational goals more efficiently. It is this understanding that has been commonly used in educational technology, where media act in the delivery sense, doing what is proscribed, transmitting information. Media in this light, present a prepackaged, unalterable piece of instruction. A good example is the filmstrip. Content, pace, organization, and goals are programmed as in teacher proof textbooks. Computers and media have been traditionally conceived of as tools.

Tools are used to achieve specific goals. A tool improves efficiency by amplifying and extending the task for which it is intended, but does not qualitatively improve instruction or make it more effective; here Clark was right. Changing 'media' in this context, has no effect, save perhaps efficiency. Used to deliver the same instructional method, the potential of the computer to extend human cognitive capability remains unfulfilled.

A broader conceptualization adopts a definition from biology; a medium is a condition that is conducive to growth. A 'cognitive' medium is one that provides an environment for intellectual growth. Such a shift alters our perspective of how computers should be used in education, and focuses on their generative use.

If we view computing as a medium, a condition for cognitive growth, we will change our understanding of how computers can be used (Kay, 1990). Conceptualizing computing as a medium rather than a tool changes our notions of how computers should be used in education. This approach shifts the focus from representative use (i.e. as a delivery system) to generative use for construction.

8. Implications

The changes in society and the development of personal processing capabilities caused by computers will have extensive implications for education. When used generatively, computers may affect how people think, how people learn, and how we understand and evaluate computer-enhanced cognitive processes. Moreover, as computers begin to be used extensively in education, researchers will need to examine questions that have not been raised previously.

8.1. Computing may change how people think

The ability to manipulate information or ideas with the assistance of a computer is an important skill that humans can learn and apply as a cognitive strategy. But will such skills have lasting cognitive residue? Luria's examination of "preliterate" cultures suggests that writing yields a conceptually different understanding of the world, of logic, and of discourse. Deprived of the technology of text, preliterate Russians exhibited logic that was less sequential, less linear, and more experiential.

> Persons who have interiorized writing not only write but also speak literately, which is to say that they organize, to varying degrees, even their oral expression in thought patterns and verbal patterns that they would not know of unless they could write (Ong, 1982, p. 56–57).

As books and writing changed the way people think and learn, so computer use that enables information flow and conceptual change may stimulate similar changes in our mental organization and thought processes.

If computers change the way that people think, then research is needed to illuminate and define the differences between computer literate and non-computer literate thought. Our present school system generally values linear-logical thought patterns over other learning styles. How will schools react to students who possess well-developed computer skills and non-linear logical thought patterns? Linear thought and linear logic are based on a directed, sequential organization of text that may be supplanted (or supplemented) by a dynamic non-linear system.

8.2. Computing may change the way people learn

Teachers often require students to complete academic tasks that have a level of rigor in their fulfillment (e.g. term papers, projects, etc.). Term papers, through the processes of finding, researching, assembling, analyzing, and presenting information on a given subject, are intended to force cognitive activity and the development of intellectual skills. Some content understanding is desired, but the methodology of the term paper is also considered an important learned lesson. The pace and activity of the successful paper allow time for reflection and reiteration; non-performance tends to be easily recognized.

Computer technology has created new tasks that students can complete. For example, teachers often require students to develop web pages or multimedia presentations as alternatives to more traditional tasks. Implicit in their use is the belief that such activities will have similar cognitive effects as their predecessors. However, the cognitive impact of such activities is unknown.

What types of tasks are likely to stimulate learning? As outlined in this manuscript, educational computer use has often been representative, focussing on instructional delivery. Such uses do little to engender the effort required by many for effective learning. In general, educational activities should be designed to stimulate cognitive effort, and to integrate the computer into that effort. A primary heuristic is that educational computer uses should require that more cognitive effort goes into the computer (i.e. is provided by the learner) than comes out (i.e. is delivered by the system). Learners should provide ideas, structures, information, and in some cases motivation to the learning process.

8.3. Computers may change how we conceptualize and evaluate intelligence

There is considerable interest in how ability should be measured. According to Olson (1977), intelligence is skill in a medium. Media may change how we evaluate

and understand intelligence. Is a choice of medium, language or symbol system a determinant of intelligence? With the advent of broadly based computing, the medium of computing changes the rubric of intelligence away from mere information and skill with text toward the ability to solve problems.

The skill and capability of computing needs to be used and taught as such; it is a skill that is a part of advanced cognitive strategies, an extension of human mental capacities. The 'basics' of reading, writing and arithmetic are cognitive skills, most valuable in their flexible application through life. They are used as part of methods of solving problems and learning. Computing is a new basic — a new language — of thought and expression.

9. Conclusion

Clearly, how computers are used is the key to their effective use and exploitation of their vast capabilities. We have examined some of the shortcomings of computers in education; traditional achievement has not changed through the use of computers to apply or deliver the same instructional methods.

Historical use of computers has followed the pattern of previous introductions of media into education, with basically the same results. Our approach to using computers in education follows our basic beliefs in the nature of education. The theoretical grounds of our practice (e.g. instructivist or constructivist), drive computer use. Changing the guiding educational theory will change the directions for the use of computers.

Defining the computer as a tool, something used to deliver instruction to the student is limiting. Such an approach uses only part of the capabilities of a medium; the communicative or representative functions. It fails to acknowledge the generative potential of the medium. Constructing knowledge is recognized as a different theoretical orientation to learning, one which the learner investigates and creates using various media or languages: writing, mathematics, scientific discovery, paint, and computers.

Humans use media as part of their cognitive strategies. We write, we talk, we compute to examine and create, and this process is at the heart of the value of computers to education.

> In the popular mythology the computer is a mathematics machine: it is designed to do numerical calculations. Yet it is really a language machine: its fundamental power lies in its ability to manipulate linguistic tokens — symbols to which meaning has been assigned (Winograd, 1984).

Our society and learning will change; Gutenberg et al. and the subsequent Reformation and Enlightenment demonstrate this through similar historical evolutions such as the adoption of movable type. Other shifts in the nature of our means of thought as a society have occurred; we are in the midst of such a change and it will have a major impact on the nature of education.

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