FROM REAL VIRTUALITY IN LASCAUX
TO VIRTUAL REALITY TODAY:
COGNITIVE PROCESSES WITH COGNITIVE TECHNOLOGIES

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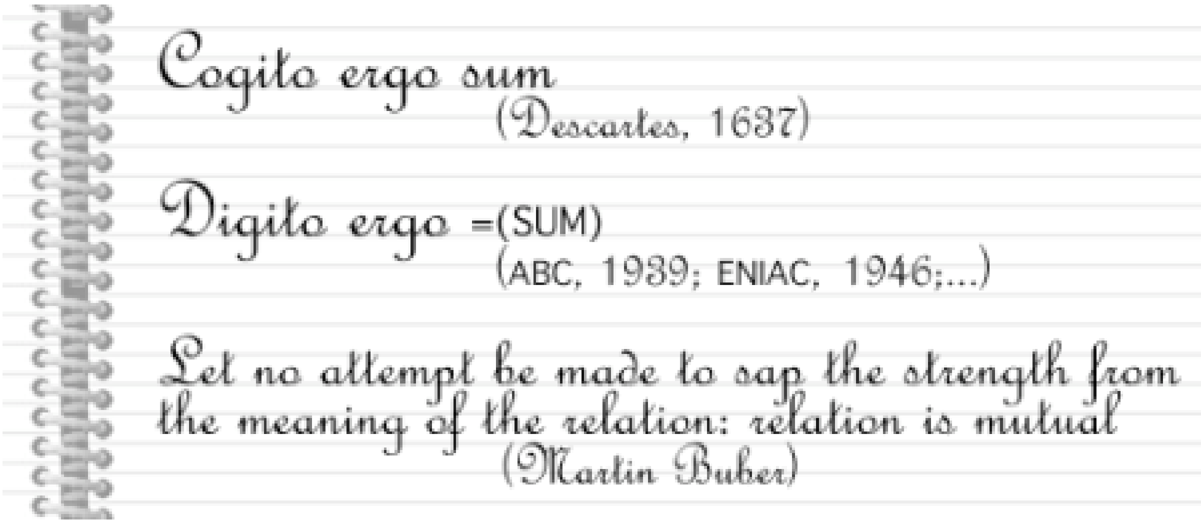
RUNNING HEAD: COGNITIVE TECHNOLOGIES



Fifteen thousand years ago, the Paleolithic denizens of the Lascaux, Pechmerle or Altamira caves labored to represent aspects of reality which were vital to their life: the animals on which they fed. A crucial motivation for these creations was suggested to be their belief in the power inherent in the representations and imitations of reality to affect and modify aspects of that reality (Hauser, 1951; Fisher, 1963). The hunter who masqueraded as the animal he wished to hunt, and who through identification with the animal intended to increase the yield of the hunt, used the power of imitation to control reality. The cave paintings were not just representations of reality; they were conceived as reality itself (real virtuality?…), and any action directed at them (such as the throwing of arrows or the casting of spears) signified an action affecting a reality destined to take place (virtual reality?…). The representations are a human creation, but their presentation on the walls of the cave evoked a complex relationship between the creator and his creation with regard to the represented reality. In more contemporary terms, this situation can be seen as ancient evidence of the reciprocal relationships between the means and products of knowledge-technology, and the thoughts and beliefs of the creator of these technological means and products.

Perceptions, beliefs and knowledge about ourselves, about the world around us and about the cosmos, have undergone a number of essential transformations since humans first endowed their cave paintings with qualities representative of the actual hunt. A common claim is that these transformations are not a consequence of any change in “hardware”, i.e., in the physiological characteristics of the human brain. For more than one hundred thousand years, the human brain has remained stable at a volume of about 1,300 cubic centimeters and the configuration found in modern humans, the Homo Sapiens Sapiens. Yet with the same physiological infrastructure, human beings in different periods have created different or even opposing conceptions and systems of knowledge.

A typical example is the drastic transformations in conceptual perspective (formal theories), and intuitive approach (personal conceptions), which characterize the evolution and development of human's perception of the universe. Some other examples include the following. A known Egyptian drawing portrays the firmament's divinity represented as an arch (the sky) wrapping the earth, who eats the sun every day in the West, thereby causing night, and who releases it in the East for the beginning of a new day. After about two thousand years of the prevailing cosmological theory of Aristotle, according to whom the celestial elements are organized in perfect order in eight layers which revolve around the earth, Copernicus removed the earth from the center of the universe and shifted it to the heavens. Additional conceptual transformations succeeded from Galileo to Kepler to Descartes to Newton and so on, complementing, expanding, contradicting and replacing each other. And conceptual transformations continued not just with regard to the cosmos, but also with regard to every aspect of the natural and artificial worlds in which we live (Kuhn, 1970; Simon, 1985).

To the range of factors which presumably influence the development of knowledge, theories, beliefs, and conceptions, the present paper addresses a specific factor: the knowledge technologies with which we interact. This chapter presents further elaboration on the claim that the development of knowledge, skills and cognitive processes is influenced by the demands and constraints presented by available knowledge technologies (Olson, 1985; Pea, 1994). From this perspective, cognitive processes are viewed **not just as a basic characteristic of mind, but also as a consequence of the interaction between cognitive structures and cognitive technologies**.

At this point, it is appropriate to define "knowledge technology" and "cognitive technology”, as these two terms occur throughout the chapter. “Technology” may be defined as human knowledge applied in solving problems and in the creation of the artificial world (Mioduser, 1998). Since the first creatures we call “humans” begun to solve problems by means of modifying nature, they –we- initiated the exciting enterprise of devising the artificial world.

Once referred to as the “Man-made world”, we will prefer to use here a broader definition: the “Mind-made world” –all human mind’s products (either symbolic or physical) aiming to cope with problems and satisfy needs (e.g., a theory, a chair, a computer).

Technology serves to complement and augment natural human abilities -such as vision beyond the distance at which the unaided eye can see or on microscopic scales, or movement from one place to another at speeds which far exceed the speed of walking or running (McLuhan, 1964). Knowledge or cognitive technology may be defined as all the means (either instrumental or methodological) which contribute to the completion and expansion of the natural abilities of the human mind, in processes relating to the handling of knowledge, thinking, learning and solving problems (Pea, 1985). Examples of cognitive technologies are: writing and all kinds of symbol-systems, the various types of measuring instruments and data collection tools, calculation tools, means for storing and processing knowledge, means for simulating events, phenomena and processes, or planning methods.

Technologies for the handling of knowledge (generation, organization, storage, processing, retrieval, and transmission) are among the quintessential products of human reason. Between these cave paintings and the feats of virtual reality that are materializing before our very eyes, lies a rich history of the development of knowledge technologies. Inspection of the reciprocal relationship between knowledge technologies and human reason reveals a complex system: (a) knowledge technology is a product of reason; (b) while being knowledge itself, it is intended for handling knowledge; (c) the handling of knowledge itself, again, is a vital function of reason, which (d) utilizes technology (its product) to carry out that same function. These intricate relationships have long since preoccupied those interested in knowledge technologies, and such reflection is of unparalleled relevance in today's microprocessor-based digital-technology-world. Below I will survey various interpretations of these reciprocal relationships, and the way in which these are reflected in learning environments and in computer-based teaching aids. The survey of the different approaches will include references to published theoretical and empirical work as well as brief descriptions of research projects by our Knowledge Technology Lab researchers at Tel-Aviv University's School of Education.

INTERPRETATIONS OF THE RECIPROCAL RELATIONSHIPS BETWEEN COGNITIVE PROCESSES AND KNOWLEDGE TECHNOLOGIES

Key questions regarding the nature of the reciprocal relationships between technology and cognitive processes were already raised more than two thousand years ago by Plato. In response to a question posed by his student Phaedrus, Socrates refers to one of the gods in Egypt who presented to the King his recent invention, writing: *"Here, O king, is a branch of learning that will make the people of Egypt wiser and improve their memories: my discovery provides a recipe for memory and wisdom*" (Hamilton & Cairns, 1961 pp. 520). Writing is presented as a new and powerful cognitive technology that may liberate the mind from the necessity of carrying a large number of details and facts. By allowing the storage of the knowledge elsewhere, "outside" the mind, it now becomes possible to divert valuable cognitive energy to more complex thought processes. But, King Tammuz' response was not long in coming: "…*If men learn this, it will implant forgetfulness in their souls; they will cease to exercise memory because they rely on that which is written, calling things to remembrance no longer from within themselves, but by means of external marks. What you have discovered is a recipe not for memory, but for reminder*". And moreover, "… *by telling them of many things without teaching them you will make them seem to know much, while for the most part they know nothing*".

This sweeping criticism of Tut's invention is interesting for a number of reasons. First, it clearly establishes the parties to an argument which nowadays, when computer and communication technologies are being introduced into schools, is still a very topical one. One party stresses the potential inherent in a technology designed to carry out processes which up until its appearance were exclusively performed by human reason. The other party points out the dangers involved in relegating a growing number of human mental functions to technology, lest this lead to degeneration of human cognition. Second, the king doubts the quality of the wisdom created by means of the technology. Replacing students' own involvement in creating knowledge, the appropriation of externally represented knowledge can, in his view, only lead to "*seemingly rather than truly wise"* people. Finally, the king warns of another factor which may generate "knowledgeable" but actually "ignorant" people: the depreciation of teaching (as perceived by the philosopher) as essential means for negotiating knowledge. Again, this is a very contemporary issue in view of the claim that technology is now making it possible to create environments in which the student learns without being taught (e.g., "Logo", Papert, 1980).

A number of valuable conclusions can be drawn from Plato's discussion regarding writing. First, there is the very idea that the interaction with knowledge technologies affects cognition at various levels, e.g., regarding the nature of acquired knowledge and skills, the strategies for the acquisition, storage, and retrieval of knowledge and skills, or the mental modeling of aspects from the physical and social worlds. Second, the perception of this interaction and its value is affiliated with, and shaped by, people's overall philosophical, cultural, and moral conceptions regarding cognition, learning and teaching. Finally, the need to reformulate and reconsider essential questions regarding this interaction becomes crucial whenever a new relevant technology is developed. Today's information and communication technologies embody processes once the sole preserve of human cognition. As such, the interaction between natural (human) and artificial cognitive processes becomes a fascinating field for inquiry and reflection.

For more than five decades, since the appearance of the first electronic digital computers and associated technologies, these complex reciprocal relationships have received various interpretations in the form of both theoretical and research work. In addition, these different approaches have had their counterparts regarding the educational implications of the integration of the technology into teaching and learning processes. In the following sections I will briefly refer to nine approaches for analyzing and discussing these relationships, along with their implication for education. From these different perspectives cognitive technologies are conceived as supporting, respectively, the acquisition, extension, consolidation, externalization, internalization, construction, collaborative creation, compensation and evolution of cognitive processes and skills (see Figure 1). Regarding practical implications, the various approaches have found their way into the educational arena in the form of computer or network based learning environments and tools. Next we will refer to each approach, along with examples of their instantiation by means of educational technologies.

Figure 1: Approaches to the description of reciprocal relations between cognition and technology

COGNITIVE TECHNOLOGY supports the	**acquisition** **extension** **consolidation** **externalization** **internalization** **compensation** **construction** **collaborative creation** **evolution**	of COGNITIVE RESOURCES [e.g., knowledge, skills, processes, metacognition]

Acquisition

In the sixth century Pope Gregory claimed that the sculptural pieces in the churches are the books for those who are not able to read. This claim is archetypal of the deeply rooted perception of the function of cognitive technologies that view these as powerful means of supporting the acquisition of knowledge and skills. This perception is embedded in the rationales for (educational) use of a wide range of tools and means along history, e.g., visual and mnemonic aids in pre-literate societies, the book for the last 500 years, or today's computer assisted instruction (CAI) software packages.

In pre-Gutenberg times, churches were considered encyclopedias of glass and stone. These immersive environments fulfilled didactic functions, served as content conveyers (e.g., knowledge, values, norms) and memory agents, by means of systematic resources (e.g., conventions regarding color usage, motives, order and sequence of images). A popular learning aid among Middle Ages' scholars and liberal professionals was the "Ad Herennium", a book aimed to teach techniques and strategies to empower memory, a key cognitive resource in those times (Burke, 1985).

In the transition from the print to the digital era, the programmed instruction model was developed (Garner, 1966). The model incorporates principles based on the behaviorist approach towards learning (e.g., reinforcements, repeated practice), and translates them into a systematic repertoire of instructional methods and techniques (e.g., meticulous "dissection" of the topic or task into discrete units or frames, formulation of clear operational objectives for each unit (and success criteria), precise definition of sequences of units, and planning of reinforcements). First instantiated in mechanical teaching machines (e.g., Skinner machines), the model found its optimal instantiation with the advent of computer technology, in the form of classical CAI (Venezky & Osin, 1991). Notwithstanding the numerous transformations in the model components along several decades (e.g., in the complexity of the underlying branching/adaptive algorithm; in the incorporation of multiple representational resources -text, still images, sound, video- and interactive modes; or in the didactic value of the feedback reinforcement supplied), its essential principles still characterize many of the instructional products being developed today even within the Internet environment (Mioduser et al., 1999).

The above examples, and countless additional teaching means developed throughout the times, are the products of a common approach: the perception of cognitive technology as powerful facilitator for the acquisition of knowledge and skills.

Extension of Natural Capabilities

This approach adopts the perception of any technology as an extension of people's natural capabilities (McLuhan, 1964). Tools and machines extend and augment the activities of the muscular system; the means of locomotion - the locomotive ability of the legs; and the means of shelter (clothing, housing) by providing more efficient protection than that naturally provided by the skin. In a similar fashion, cognitive technologies expand and augment the functions of the central nervous system: they aid the memorization of large quantities of knowledge through means external to the mind (books, CDs), the performance of fast and precise calculations (the multiplication table, calculator), or the running of knowledge-intensive decision making processes (expert systems).

Writing is an instance of a technology that plays a crucial role in extending natural capabilities, as discussed above. Leibnitz, in the 17th century, referred to various symbol systems such as "Letters, words, chemical symbols, Chinese signs and hieroglyphics, music notes, arithmetic and algebra, and all the others we use for thinking... their usefulness increases the more they express the concept to which they refer, and thus they serve us not just for representation but for thought too".

Today, generic tools for processing words, images, sounds or numbers are part of the students' learning environment in all subject areas, extending the learners capability to carry out complex manipulations of information in varied representational forms. In addition, communication networks enhance students' ability to interact with large repositories of knowledge, as well as with people (e.g., teachers, peers, experts), beyond school time and space constraints. The "extension of natural capabilities" approach is implemented in learning environments in several modalities or through a number of metaphors:

a. The "Olympic games motto" metaphor (i.e., "Citius, Altius, Fortius"), by which technology is perceived plainly as empowerment means (e.g., amplification) for the learners' cognitive abilities.

b. The "division of labor" metaphor, by which the learner concentrates on performing high order cognitive functions delegating functions that are routine, repetitive, time consuming and computation-extensive to the technology.

c. The "artifactual extension" metaphor conceives the technological device in use by the individual as inscribed within his or her cognitive contour (e.g., the blind person's cognitive contour includes the cane; or the searcher's cognitive contour includes the browser, the search engine, the complex communication network and the servers containing the target information) (Gibson, 1986**)**. In an extreme version of this metaphor, Logan (2000) suggests that "if media are extensions of our psyches, the interconnectivity of the internet means that its users will become extensions of each other's psyches" (pp. 31).

Activation and consolidation

In this approach, technology constitutes a facilitating milieu for the activation and consolidation of cognitive skills and abilities at various stages of the learner’s cognitive development (diSessa, 2000; Lajoie & Derry, 1993). The unique features of the technology supply opportunities, as well as demands, for the activation of otherwise either latent or underdeveloped cognitive resources.

Classic examples of this approach relate to the use of generic tools, such as spreadsheets, word or image processors, or search engines. Most of the core skills involved in using these tools are normally acquired without any connection with computer technology, e.g., writing, drawing, information-search or number-manipulation related skills. But the claim is that the use of the technological tools triggers the emergence of qualitatively different manifestations of these core skills (McCullough, 1996).

In the spreadsheet example, the abilities required for the definition of the mathematical content of each individual cell are not exclusive to this tool. But the spreadsheet enables the development of more sophisticated abilities, e.g., the perception of the tool as phenomenon-modeling means, therefore implying the perception of the problem to be solved as a "modelable" entity; the ability to define a problem in terms of an array of cells, their content, and the link-paths among them; or the ability to selectively manipulate cells' values to explore hypotheses.

Externalization

Cognitive technologies allow external presentation to the mind of the process and products of cognitive activity. We make use of various types of artifacts (such as writing, sketches, diagrams or graphs) as thinking aids for the presentation, organization, analysis or summary of an idea or of a problem solution (Miller 1984).

The support of cognitive process presentation is provided by various types of computerized tools. For example, information retrieval software allows texts and images received during a search to be copied and added to one's own electronic notebook so as to create a personal document relevant to the current task (Oren, 1992). Moreover, the queries and searches made are also recorded. These documents constitute a picture or reflection of the search process, of the unfolding and development of the queries, of decisions regarding the relevance of the material, and of decisions regarding the structure of the document formed..

Another form of externalization support consists of computer tools which incorporate mechanisms aiming to explicitly encourage students' reflection on their performance. An example of this kind of tool is a program for the investigation of meteorological phenomena and their prediction ("The Weather Machine", Mioduser, Venezky & Gong, 1998). The learning is conducted as a dialogue between the learner and a computerized partner. At a certain point, they both propose a weather forecast based on the meteorological data defined at a preceding stage. If there are discrepancies between both forecasts, the student is asked to examine the events she included in her forecast which the computerized expert did not include, and to point out which specific factors (such as temperature, cloudiness or barometric pressure) led her to the inclusion of these events. The computerized expert examines then the possible effect of the factors mentioned by the student, presents its feedback (e.g., "It is possible that factor X will cause strong winds from the east, but because of the interaction between factor X and factor Y it is not plausible for this phenomenon to occur"), and asks the student to suggest how to proceed with the discussion. In programs which incorporate such mechanisms, the processes of externalization, thinking-about and reflection are intentionally and explicitly supported by external aids.

Perhaps a strong representative of the situation at which technology supports externalization of thinking processes is computer programming, and in particular educational programming (diSessa, 2000; Papert, 1980). A program code is an explicit mirror of the programmer's problem-solving process. When a bug occurs in a program this is in fact a programmer's (conceptual) bug, e.g., a branching point incorrectly defined, a missing variable, or an endless-loop construct. Navigating the code, reconstructing the (unexpected) process, locating and repairing faulty segments, are a process in which the program and its programmer's thinking are simultaneously debugged. Even with today's sophisticated tools, due to which traditional programming has been relegated behind-the-scenes far from the user's apparent space of action (e.g., using friendly Web-pages editors we do HTML tagging without actually writing source code, or using a word processor’s formatting menus we generate printing specifications within a document without actually dealing with code), debugging remains a fundamental reflective process.

Internalization

Cognitive scientists investigate information processing processes carried out by "cognitive beings" ("Informavores", Miller, 1984; "Cognizers", Pylyshyn, 1984), taking place in either the human mind or a machine. Many years of research have yielded formal and computational models of various aspects of the information processing process (such as perception, representation of information, memory storage and retrieval, problem solving). All these are intellectual artifacts, the products of human reason, yet they simultaneously serve as aids to the functioning of human reason. There is a large variety of well-known intellectual artifacts which are often found in schools (e.g., the multiplication table, the set of rules or operators for the solution of algebraic equations, grammatical rules, procedures for the analysis of a literary work). The assumption which guides the teaching of these artifacts is that once they are assimilated by learners they enrich their cognitive functioning (Ohlson, 1993). A similar claim is maintained with regard to work with sophisticated knowledge technologies.

Some work belonging to this approach focuses on the internalization or internal mapping of qualities implicitly present in the technology. The interaction with the technology is supposed to leave cognitive traces which go beyond the work as such, and may be generalized for use in new situations and areas (Salomon, Perkins & Globerson, 1991). As an example at a basic level we can consider the everyday use of metaphors originated in the interaction with technology while referring to situations (individual, social) not related to technology, having became useful language as well as thought devices. At a more complex level we can relate to people's cognitive assimilation of defining components of the continuously developing visual language of our time (from the first movie scenes shouted, through television evolution, to the current digital worlds). Significant examples are our ability to visually reason in terms of (and feel comfortable with) zoom-ins and outs beyond our natural capabilities, simultaneous multiple perspectives, visual transformations, or fast bombardment of visual fragments out of which we compose stories.

From a different perspective educators deal with the explicit instruction of complex cognitive aids (Novak, 1990; Wideman & Owston, 1993). In the project reported by Mioduser and Santa Maria (1995), 5th and 6th grade students worked in a computerized environment to create tree-like structured knowledge bases ("The Knowledgeable Tree"). The product is a (textual and visual) knowledge base which the students or their classmates can navigate in order to carry out tasks and write projects. All stages in the construction of the knowledge tree (e.g., mapping the content, defining the knowledge units or nodes, establishing hierarchy levels and links) are performed following the conceptual model embedded in the computer tool. The expectation is that this model will be assimilated as a powerful knowledge-manipulation resource to be activated in future scenarios. Indeed, the study showed clear impact of the learning not only on the students' knowledge representation abilities, but also on their propensity to use the analytical, organizational and representational skills which they had applied in the course of working with the technology outside the computer environment.

Construction

This approach focuses on the role of technology in the construction of knowledge and skills. According to this approach, artifacts (including computerized environments) receive the status of "objects to think with" (Granott, 1993; Kindfield, 1994; Papert, 1980). The umbrella of this approach is a pretty wide one, and it covers various types of observers of the reciprocal relationships between technology and reason from a number of different theoretical viewpoints, such as constructivism/constructionism, situated cognition and cognitive apprenticeship.

According to the constructivist viewpoint, learning is a process of knowledge structuring. To this, constructionists adds that this structuring will be significantly supported by constructing something in reality - “a public entity” (Papert, 1991). Computerized environments, like the Logo language, or technological systems such as Logo-controlled robotics kits, enable this sort of construction therefore fostering "the turning of making into thinking" (Mitcham, 2001, pp. 31).

From the situationist point of view, knowledge structures are anchored within the context in which they are developed, and they have a direct relationship with the situation, the tasks, the objects and the human partners in that context (Brown, Collins, Duguid, 1989). Knowledge technology makes it possible to create rich and significant learning tools supporting natural processes of learning (e.g., microworlds, Papert, 1980) or inquiry processes in authentic activities (e.g., scientific visualization learning tools, Edelson, Gordin, & Pea, 1999). Sometimes the use of technology is the only way for the learners to encounter a certain reality, which would have been inaccessible for them due to, for instance, complexity, cost or a high level of risk (Lajoie & Derry, 1993).

The third perspective, **cognitive apprenticeship**, addresses the need to include strategies of training and support in the learning environment, in order to help the learner in the gradual construction of knowledge and skills (scaffolding, coaching). The basic idea is to provide the learner with contextual help and to gradually remove it when it is no longer required (Brown & Palincsar, 1989). Certain computerized systems include mechanisms which combine continuous evaluation of the learner's performance with the creation of support and feedback based on that evaluation (or a student model), in an attempt to achieve maximal individual adaptation of the coaching or tutoring (Albrecht, Koch, & Tiller, 2000; Wegner, 1987).

Collaborative Creation

The core idea behind this approach is the perception of knowledge as a social construct (Vygotsky, 1979). Knowledge construction is perceived as the consequence of a social process, or at least a process which includes, in addition to the learner, an "other" with whom one cooperates and shares tasks in the process of creating the knowledge (Koschmann, 1994; Nachmias et al. 2000; Salomon, 1993). The question: "Can one expect the lone learner to think and function as a researcher or scientist (biologist, historian or physicist)?", is replaced with: "Can one turn the group (the class) into a knowledge building community, similar to those which presently advance each and every area of human endeavor?" (Scardamalia & Bereiter, 1994).

Along these lines, technology may play a number of roles. At the basic level, technology provides the physical infrastructure for the interaction, such as electronic mail or electronic discussion groups means. Yet beyond this level, one can find complex systems which support varied kinds of processes, such as collaborative writing, collaborative design, or shared annotation systems for collaborative Web browsing (Amory, 1999; Kennedy & McNaught, 2001; Verdejo & Barros, 1999).

An example of a collaborative Web-based environment is the "Knowmagine" Virtual Park for Science Technology and Culture (Mioduser & Oren, 1998). This collaborative learning site in the Internet allows students to enter the park from different locations at the same time, walk through its 3-D graphic space, activate exhibits, consult the knowledge center, perform short term learning tasks interacting with occasional distant visitors, as well as long term collaborative projects with previously committed distant fellows (e.g., a replica of Galileo's trial in the form of a two-week role-playing event).

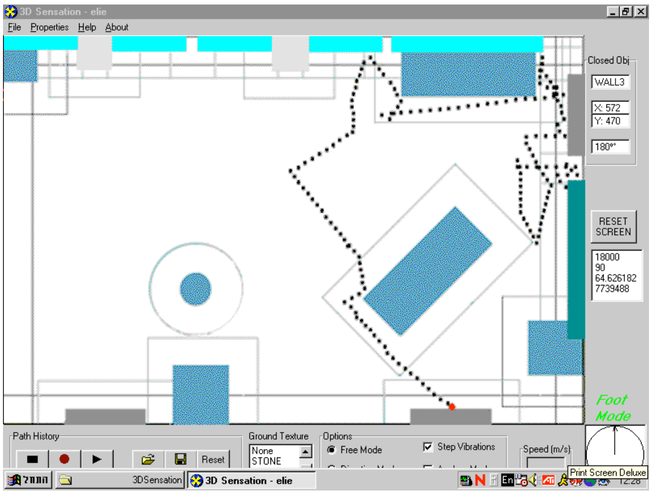
Unique collaborative entities, which emerged with the development of network technologies, and continue to evolve into interesting configurations, are virtual learning communities (Jones, 1997). These are defined as social spaces where people with common (academic or professional) interests carry out learning transactions. By means of varied collaborative models (e.g., online workshops, peer-review and friendly critique of ideas, synchronous and asynchronous discussion groups, info-boots) individual and social learning takes place, continuously enriching the shared body of knowledge. Oren et al. (2000) suggest a comprehensive model for virtual learning communities, or Learnets, defined as novel educational systems based on the combination of three components: a virtual community (social dimension), hosted by an appropriate virtual environment (technological dimension), and embodying advanced pedagogical ideas (educational dimension). The model by its different variables (e.g., extent of presence, alternative-status definitions, immersivity, multi-user features, communication means, educator functions, hypercurriculum) aims to serve for both the development and evaluation of virtual learning communities.

Compensation

By this approach technological means are perceived as "cognitive prostheses", providing compensatory resources for the development of cognitive abilities whenever fundamental resources are impaired (e.g., as in blindness or quadriplegia). Cognitive and developmental theories stress the crucial role of interaction with the world (the natural, artificial and social surroundings) for the evolvement of cognitive functions and skills. Partial or total impairment of an essential interaction channel or means (e.g., vision, hearing, motor ability) seriously affects a person's cognitive functioning. Here, cognitive technologies may supply alternatives in place of the damaged path, providing substitute resources for appropriate cognitive development or functioning.

Recent work by us within this approach relates to cognitive-technological support for vision-impaired and blind people. In one case a computer tool was used to supply semi-intelligent remedial treatment for spelling difficulties of vision impaired people (Mioduser, Lahav, & Nachmias, 2000). Further recent work focuses on supporting blind people's cognitive mapping of new (unknown) spaces by navigating a virtual model of these spaces based on haptic and auditory feedback (Lahav, & Mioduser in press). The work within the force-feedback environment supports cognitive processes such as holistic recognition of the space (as opposed to linear or object-to-object paths characteristic of cane-based navigation), or the composition of spatial advance-organizers to be probed and corrected during the actual navigation of the real space (Figure 2).

Figure 2: Dynamic log of a blind person's navigation of a new space, in a training session using the haptic-feedback-based virtual environment



Another example relates to the development of spatial knowledge (e.g., directionality, perspective taking) by severely handicapped persons. Developmental theories claim that motor activity has a critical role in the evolvement of cognitive abilities, among them spatial knowledge. In the case of severe motor impairment, a person is deprived of the possibility to actively manipulate objects in the world, and therefore this may affect her/his cognitive development. In a recent work, cerebral palsy subjects with quadriplegia worked with a robotics system to deal with spatial problem-solving (Gliksman, 1999). The system served for the mediated manipulation of objects, supplying the subjects with the possibility to act on the physical world and solve spatial problems in ways that would not have been feasible without the technology.

Evolution

This controversial approach embraces the biological model of evolution and adapts it to analyze and explain in philosophical/social/cultural terms the role of the interaction between humans and technology in shaping cognition. The main claim is that when human evolution is examined (against that of other living creatures) one unique and distinctive aspect of it, cultural evolution, must be considered. The evolution of living creatures is mainly endosomatic and is expressed in changes in various organs. Humans are mainly characterized by exosomatic evolution, which is expressed in the creation of new organs -artifacts- outside the body (Olson, 1985). The new external organs related to information generation and handling (such as books or computers) crucially affect the development of new cognitive abilities.

A classic example of this approach, frequently given in the literature, is the shift from spoken to written language (Havelock, 1973). The invention of writing has clear cognitive implications, such as the liberation of memory from the need to bear the tremendous body of knowledge which was hitherto transferred orally from one generation to the next. This shift decreased the importance of the skills which until then had been used to organize and represent knowledge in a way appropriate for memorizing (rhymes, sayings, a powerful plot). At the same time it provoked the development of new skills such as the ability to derive conclusions regarding (large sets of) logical statements which are stored by means of memorization tools external to the mind. The interaction with cognitive technologies leads to an intellectual or social evolution, which finds expression in the reorganization of cognitive abilities and the development of new skills, structures and cognitive functions.

Recently Logan (2000) suggested that "the computer and the internet are the most recent in a long series of techniques and technologies that organize human thought", and that these "are part of an evolutionary chain of languages that also includes speech, writing, mathematics, and science"(pp. 61-62). These languages are presented as evolutionary solutions generated vis-à-vis the increasing complexity of human thought. Regarding computer technology, it is enough to mention such issues as the cognitive connotations of different approaches to computer programming (e.g., algorithmic, functional, object-oriented), or of the very process of debugging, which have no precedent in previous technologies. The sixth language, the Internet, owns unique semantic and syntactic characteristics therefore implying new cognitive modes (e.g., hypertext, which demands novel approaches to writing and reading; or search processes, which demand appropriate retrieval skills and strategies in order to exploit the power of immediate accessibility to every unit of information in congested data-bases).

ADVANCED KNOWLEDGE TECHNOLOGIES IN EDUCATION

Technology continues to develop at a rapid- pace. There is no sense in trying to predict how the scene will look beyond the immediately foreseeable future, and this too must be done cautiously; for an innovation which seems to be no more than a technical development may suddenly combine with other innovations resulting in a qualitative (not just a quantitative) leap (Tubin et al., 2003; Venezky & Davis, 2002). Reality indicates that the assimilation of technology in education is a very slow process (not to mention the almost certain inability of educational systems to cope with updates and innovations taking place daily). Against this backdrop it seems that any analysis of the way in which the reciprocal relationship between technology and cognition is expressed in education must maintain a comprehensive outlook, rather than latch onto particular technical aspects which will undoubtedly change and improve in the future. Bearing this perspective in mind we shall conclude with the presentation of a number of issues, or evolving questions, which are worth considering.

Fostering an integration of approaches

The above presentation and classification of the various approaches was of course done for purposes of survey and analysis. In reality, one may view a certain computerized environment as embodying the combined qualities of a number of approaches. An electronic spreadsheet program may serve as an aid in calculation (extension), as a tool for building and representing a model of a phenomenon (externalization), as a tool for the acquisition of skills for analyzing a phenomenon by means of various representations (construction), and more.

Any learning process comprises many stages and functions. Determining the importance of a tool which serves as practice aid (through repeated experience) supporting the automation of a skill, as compared with the importance of an inquiry tool which serves to discover causal relationships between factors, must be relative. This determination is a function of needs and goals. It seems that the analysis of these needs and goals, in combination with a theoretical perspective, must guide the shaping of computerized environments appropriate for supporting the various functions, while combining various modes of interaction between the learner and the technological environment.

The action space for cognitive processes

One of the more interesting implications of technological development is how it fosters increasing flexibility and expansion of the action-space of cognition. The technology which, hundreds of years ago, enabled humans to examine the celestial bodies more comprehensively than they were able to do with the naked eye, has led to an essential transformation in the perception of the universe. Today, technology creates a space with ever-expanding boundaries. Let us take the prehistoric cave as metaphor for present-day technology. By means of the equipment of virtual reality (head-mount, glove), a cave (any simulated reality) surrounds us directly, encompassing us as an additional layer beyond clothing. On the other hand, by means of computer communication technologies the cave expands up to the entire world, in the form of a giant network connecting millions at every point on the face of the earth: the “Cyberspace” (Rucker, Sirius & Mu, 1992). Where is the school realm (its physical and human boundaries) actually located on the continuum between the private “cave” and the networked world?

Learning institutions have, and will in the foreseeable future continue to have, definite physical boundaries, with a certain structure and organizational configuration. We may refer to the school and the institutionalized learning activities taking place within it, as a window or a frame encompassing a defined field of vision. Then we may ask: Can we move this frame back and forth, according to individual and social needs, along the above mentioned continuum between private and collective cognition in cyberspace? What additional (new, other) schooling and learning functions, modes, and configurations must be developed? What kind of support may cognitive technologies supply for the definition and implementation of these new functions and modes?

Theory versus reality

There is harsh criticism of the attempts to use technology for teaching and learning, which may be summed up by a statement like: "They're throwing computers into schools but nobody knows what to do with them". The criticism, in other words, is directed against an over-enthusiasm for technological gadgets and effects without proper reference to educational content and needs. It has also been claimed that in many cases, technology has been used to merely duplicate existing methods (Scardamalia & Bereiter, 1994). Many educational ventures are directed at exploiting technological potential rather than at satisfying educational needs, and are technology-based rather than educational-theory-based (Mioduser et al. 1999).

The above surveyed theoretical approaches regarding the interaction between technology and cognition, are still very far from materialization in the everyday reality of schools. We must learn to take advantage of the accumulating theoretical knowledge as leverage for the mindful implementation technological advances in education, and not just as a means of explaining why a particular application is or (in many cases) is not significant to learning.

This task is not an easy one. It is therefore of great importance to drive for a proper combination and just balance between research efforts, development efforts, and application efforts, in order to achieve a better assimilation of cognitive technologies into educational processes and practices

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The walls of our present cave are once again full of representations of reality, but now the walls are not real nor are the paintings they bear; everything takes place inside a helmet, goggles, a glove and a tiny processor. Today, like fifteen thousand years ago, the helmet-wearer manipulates representations of reality instead of manipulating reality itself, but the difference between the two situations is highly significant:

> <u>The caveperson used reason to manipulate reality</u>
> (Representing reality and manipulating that representation, in the belief that s/he was manipulating reality.)
>
> <u>The present day helmet wearer uses (virtual) reality to manipulate reason</u>
> (Representing reality and manipulating that representation, in the belief that s/he is acquiring skills or knowledge.)

Even if we refer to less sophisticated means than those of virtual reality (such as simulations, intelligent systems, or even commonly used word or image processing tools), these imply the existence of a uniquely powerful feedback system: Reason creates technology (its products), and work with that technology influences, in turn, that same reason and its products. As to education, a deep understanding of the nature of this feedback cycles is fundamental for the appropriate assimilation of cognitive technologies (either existent or still to come) into teaching and learning processes.

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