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LEARNING IN WONDERLAND

What do Computers Really Offer Education?

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A look around tells us that computers and associated information processing technologies have had a transformative impact on many fields. There has been a crescendo in the thoroughness and depth with which one can explore data statistically. Computer models of weather systems and quantum phenomena make possible predictions and understandings unapproachable before. Routines like arranging a theater ticket or an airline reservation have become high-tech enterprises that routinely juggle a myriad of complexities in behalf of customers.

It's natural to expect that computers are having an equally transformative effect on educational practice, leading to a dramatically fresher, more engaging, and more powerful process of learning -- education in wonderland! Yet, recalling that the Red Queen in Alice and Wonderland routinely believed five impossible things before breakfast, we may pause to ponder whether one of them might be the technological revolution in education. After all, where is it?

Mavens of technology in education have announced the arrival of the millennium -- and announced it again and again. But not all that much seems to happen. Despite interesting experiments in a few select settings, the business of education plods on much as usual. The model T Ford of technology in education, the product that brings the public flocking, seems not to have been discovered yet. Or perhaps it is not there to be discovered. In fact, perhaps the expectations are all askew. What kind of help can we really look for from information processing technology?

It's understandable that more wide-eyed wonderment than results has marked the first decades of exploring what information processing technology might offer education. In some ways, new technologies of any sort have a developmental sequence resembling that of individuals, and computing in education is no exception. First came the hesitant and uncertain early steps characterized by dependence on previous behavioristic conceptions and practices, manifested in CAI- like programs. The somewhat unrealistic aspirations of shaping students' minds through programming (Papert, 1980) were quick to follow as an antithesis to the drill and practice approach, leading to much research and considerable disappointment (Pea & Kurland, 1984a,b). Next came bold flirts with artificial intelligence (e.g., Yazdani & Narayanan, 1984), and naive excitements about new technological possibilities (e.g., ICAI, ITS, multimedia, world-wide student communication networks) that carried more promise than delivery, rhetoric than actual change.

Many, although not all, of these forays have been inspired by technological opportunism. Particularly when a technology is still novel and the instructional possibilities more promissory than proven, directions are likely to be provoked by what the technology can do. Operation and function (the "Gee wizz" phenomenon) drive the formulation and construction of the justifications, and, more importantly, the actual way the technology is used. A whole instructional wardrobe of theory and practice becomes tailored to fit a new and shiny button. This is what Papert (1987) has called "technocentrism". Kochman, Myers, Feltowich, and Barrows (1993/1994) point out that such technocentric undertakings are insufficient, and we might add - naive and potentially misleading.

The Mount Everest rationale -- "because it is there" -- may provoke some useful explorations, but in the end it will not do. For example, the shortage of computers in a classroom is an insufficient rationale for team-based, collaborative learning. Similarly, the fact that students can now easily construct complex multi-media presentations is an insufficient justification for having them engage in such tasks. The possibility of having students access information from distant computerized data bases, <u>in and of itself</u>, is insufficient reason to get them involved in such activities. The real question must be whether such applications yield the

avalanche of learning they are supposed to. The rationale must come from other sources, sources that are independent of the breathtaking feats that a technology can accomplish. As Sarason (1984) has pointed out, not everything possible is necessarily desirable. And desirability is not justified by the technological possibilities; it requires independent, non-technological bases
to provide good reasons.

Well, toddler games, unrestrained excitement, and unfounded aspirations (as well as fears) are falling behind us. The childhood years of computing in education are gradually giving way to more contemplative adolescence with a more thorough search for purpose, rationale, and perspective. What is computing in education all about? What purposes is it to serve? Where, in the larger scheme of educational things does computing belong? Why -- beyond trivial reasons and justifications -- do we embrace (or shun) it? Given the potentials of computing, what would their best modes of employment in education be? And what does "best" mean in this context? How would we know to distinguish arousing rhetoric from serious consideration, shinning paths that lead nowhere from promising trails towards profound pedagogical change?

At least two important observations have become widely recognized. First, computers, in and of themselves, do very little to aid learning. Their presence in the classroom along with relevant software does not automatically inspire teachers to rethink their teaching or students to adopt new modes of learning. When students use computers for various tasks -- writing, drawing, or graphing for instance -- this usually does not radically transform what they would do without computers, although it may make the enterprise more efficient and more fun. Learning depends crucially on the exact character of the activities that learners engage in with a program, the kinds of tasks they try to accomplish, and the kinds of intellectual and social activity they become involved in, in interaction with that which computing affords. Computer technology may provide interesting and powerful learning opportunities, but these are not taken automatically; teachers and learners need to learn how to take advantage of them (Perkins, 1985).

Second, it has also become evident that no <u>single</u> task or activity, wondrous as it may be, affects learning in any profound and lasting manner in and of itself. Rather, it is the whole culture of a learning environment, with or without computers, that can affect learning in important ways. Thus, rationales for the employment of computers in education need to take into account simultaneously the kinds of opportunity for activities afforded by the technology and the kinds of changes in the real learning environment that would help realize these opportunities. Rationales that pertain only to a computer program are too limiting and often virtually irrelevant.

All this adds up to a simple conclusion about information processing technology and education: To figure out whether the contribution of computers to education is on the Red Queen's list of impossible things or a genuinely transformative force, we cannot look primarily to the technology itself. Rather, we need to look to our contemporary understanding of cognition, particularly our understanding of what good learning and higher order thinking are, how they unfold, and how to facilitate their development. Not what technology can do, but what learning demands, best points up the potential contributions of technology.

This does not mean that current views on learning can easily or straightforwardly translate into instructional recommendations (Cobb, 1994), and certainly not into blueprints for learning environments. For instance, the characterization of learning as construction sits comfortably with many quite different learning environments and pedagogical practices, although it does argue against rote learning. Nevertheless, as it has been shown already (e.g., Campione, Brown, & Jay, 1992), and as elaborated upon below, current views on learning offer reasonable road signs allowing us to map the outlines of technology intensive learning environments, their design, and ways to study them.

In such an analysis, technology plays more the role of midwife than mother, helping things along, sometimes in crucial ways, rather than in itself doing the real work of teaching. Technology serves as a set of means that allows us, in many cases for the first time, to realize the visions suggested by our understanding of thinking and learning. For instance, the design and instructional use of a program like the <u>Writing Partner</u> (Zellermayer, Salomon, Globerson, & Givon, 1991) was guided and justified first and foremost by our understanding of why and how to cultivate students' writing-related metacognitions. This understanding was based on a Vygotskian conception of how externally-provided guidance can be internalized to become self-guidance and on the assumption that self-regulation is crucial in learning. However, application of such understandings for the improvement of essay-writing needed a sophisticated technology that would afford on intellectual partnership with the writer during essay writing. An appropriate program was developed and was successfully employed, serving as the enabler or realizer of the basic idea.

Key ideas about cognition and learning

So let us begin with the nature of learning, exploring over the next pages a number of key ideas about cognition and learning that speak to the roles computers might play in education. With these ideas as a framework, we will turn to how computers might best serve education.

Learning as Constructive

Across a variety of contemporary views of learning, one central idea (some would argue a mantra-like slogan, see Cobb, 1994) provides a unifying force acknowledged by virtually all: The acquisition of knowledge is not a simple, straightforward matter of "transmission", "internalization", or "accumulation", but rather a matter of the learner's active engagement in assembling, extending, restoring, interpreting, or in broadest terms constructing knowledge out of the raw materials of experience and provided information. This notion is where Piagetian and information processing approaches meet (Resnick, 1987). This is also where individualistically-oriented ("solo") perspectives of knowledge as being in one's mind (e.g., von Glaserfeld, in press) and sociocultural perspectives of knowledge as socially distributed (e.g., Resnick, 1991) share common ground.

As a theory of learning, constructivism can be viewed as supported not just by psychological experimentation but by the very logic of what must be involved in learning. No experience unambiguously declares its significance. No message, however well-crafted, can spell out all its meanings and implications. Of necessity, to make sense of experiences, including communications in any form, the organism must assemble and extrapolate -- that is to say, construct. As Bereiter (1994) points out, the idea that students construct their own knowledge is not a falsifiable claim. If the mind is seen as a container with schemata, representations, and other objects, then they could not simply have slipped in whole by way of the eyes and ears. They must have been constructed there.

Then what kind of prescription does constructivism write for teachers and learners? The temptation is to envision learning ideally as some form of self-guided discovery, where the teacher sets the stage, provides the opportunity, and offers no more than the raw material and guidance for the constructivist process. Indeed, for some this is precisely the practical meaning of the constructivist perspective. However, Perkins (1991) among others points out that very different and seemingly effective approaches to education also sail under the banner of constructivism. While certainly powerful learning experiences can occur through discovery learning, it is far from clear that this scheme serves most learners well for most topics, and very clear that it serves some learners poorly for some topics. As Weinert and Helmke (in press) argue, students often seem to engage in effective knowledge construction in relatively didactic environments (see also Cobb, 1994). Second, students in open ended learning environments specially designed to foster knowledge construction do not always engage in it unless highly motivated. Third, as Driver, and her associates argue (1994), "Scientific entities and ideas, which are constructed, validated, and communicated through the cultural institutions of science, are unlikely to be discovered by individuals through their own empirical inquiry'' (p. 6).

Perhaps the best interpretation of constructivism's implications for education asks not what it prescribes but what it proscribes. Learning experiences that do nothing to foster, and even sometimes actively discourage, learners' manipulation of knowledge -- struggling with it, puzzling over it, trying out this and that, striving to master, understand, apply, refine, and so on -- will surely lead to little real learning. One might sum this up in the following principle, the first of several:

> #1. Constructivism: Effective learning requires that learners engage actively in manipulating the target knowledge, thinking and acting on the basis of it to revise and expand it.

Learning with Understanding

Constructivism is often identified with learning for understanding, with such paradigm cases as coming to understand control of variables, Newton's laws, or Darwin's theory of natural selection. However, the reach of a constructivist perspective is in no way limited to such cases; it includes the learning of motor skills and first languages, for instance, where the enactive abilities acquired would not normally be said to be understood so must as mastered. Moreover, the effects of practice in leading to more and more refined constructions of a particular performance do not always serve well understanding as such. Evidence gathered by Langer (Langer, 1989) suggests that, unlike the common wisdom, "practice makes imperfect" as it strengthens the welding of information to particular contexts and cues, paving the way to limited, mindless retention, highly effective in its context but quite unreflective and unlike to transfer to novel contexts. But such learning is of course constructed too. All this implies that learning for understanding requires more than the general constructivist paradigm.

One recent analysis of understanding argues that the hallmark of attained understanding is, roughly, thinking with what you know (Gardner, 1991; Perkins, 1992, 1993). Learners who can manipulate what they know -- criticizing it, making generalizations, finding relationships, devising applications, and so on -- show understanding of that knowledge. Learners who can only retrieve the knowledge in more or less rote fashion and apply it routinely to stereotyped examples may have acquired useful information and skill but do not really show understanding. Mental operations like generalizing, finding relationships, and so on, are called understanding performances or performances of understanding.

This performance view of understanding treats learning for understanding as a matter of performance acquisition, akin to other kinds of performance acquisition like learning a motor skill -- but with a difference: the kinds of performances mastered are patterns of thinking appropriate to the topic in question, for instance reasoning with a physics concept or with ideas about forms of government and social policies.

This perspective puts the thoughtful use of knowledge on center stage. The thoughtful use of knowledge in novel situations or the solution of novel problems would be impossible without understanding. Likewise, thoughtful use serves a guideline for fostering understanding: Through thoughtful use in complex thought-demanding problems and situations, better understanding evolves. This leads to our second principle:

> #2. Understanding as thinking: The hallmark of understanding something is being able to think with what you know about the something; understanding is acquired through engagement in activities that call for such thinking.

The foregoing precept characterizes understanding and its acquisition on the outside, in terms of what the learner needs to do. But what happens inside the cognitive apparatus of the learner? One plausible account looks to the creation of a network of connections between bits and pieces of knowledge, concepts, formulae, principles and propositions. This conception is based on two principles.

One principle holds that no piece of information has much meaning in and of itself; it is understood only when related to other bits and pieces. Thus, understanding lies in the connections. The two circles [OO] have no comprehensible meaning unless seen as part of a symbol system within which they may mean Little Orphan Annie's eyes, a sign on a door signifying the entrance to an outhouse, two zeros, or part of the word BOOK (Goodman, 1968). It is the relationships to other symbols within the symbol system that allows one to understand the two circles. More broadly, this suggests the image of a three dimensional semantic network in which the pieces of information constitute the nodes, and causal, correlational, associative, part-whole, and similar connections constitute the connectors.

The second principle is that such a network must be information- rich and organized in ways that support performances of understanding specifically. The denser the network of links and the more the links feature semantic relationships important to thinking with what you know, such as relationships of generality, analogy, potential application, and so on, the better will the network support such performances. In contrast, a web of idiosyncratic, more or less free associations may make one's knowledge richer, but not better understood. The density of the network assures richness of meanings whereas the orderliness of structure allows predictability and smoothness of movement from one node to another, from one part of the network to another. The following principle captures this notion:

> #3. Understanding as a network: Understanding something involves building a rich and broad semantic network of relationships in which the target knowledge sits, with links supportive of kinds of thinking pertinent to the target knowledge.

Learning as a Social Process

It's plain that the construction of richly connected semantic networks will be abetted by communication and multiple perspectives. A central role for collaborative, cooperative, socially shared learning follows (e.g., Newman, Griffin, & Cole, 1989; Resnick, Levine, & Tesley, 1991). As pointed out by Resnick (1991): "Our daily lives are filled with instances in which we influence each other's constructive processes by providing information, pointing things out to one another, asking questions, and arguing with and elaborating on each other's ideas... Cognitions about social phenomena have long been of concern to social psychologists" (p.2).

Two variants on learning as social can be identified: The weak version says that learning is socially facilitated, whereas the strong version says that learning is socially distributed: what is learned does not reside in single minds but in the collectivity, including artifacts like notes. According to the weak version, team-based learning supports the intellectual activity of the individual. For instance, "All of the responsibility for comprehending does not rest with one person and even if a learning leader fails, the other members of the group including the adult teacher, are there to keep the discussion going" (A. Brown, et. al., 1991, p. 141). Very often, this version invokes a Vygotskian conception of sociocultural learning and development. As pointed out by Brown et. al., (1991), "Because the group's efforts are externalized in the form of a discussion, novices can learn from the contribution of those more expert than they on any particular point. It is in this sense that reciprocal teaching dialogues create a zone of proximal development" (p. 141).

While the weak version emphasizes the learner's solo achievements in the group context, the strong version underscores how what is learned commonly resides in the collective knowledge of the group, extended by artifacts such as notes and physical models. Learning and thinking are not only processes that occur within individual minds but that play out "stretched over" and "in between" individuals (Cole, 1991; Lave, 1988). Achievements are jointly constructed in a social system, aided by cultural tools, and thus intelligence is not so much a property of the solitary person as it is a quality that emerges socially within the context of a joint activity (Pea, 1993; Perkins, 1993). We package these points into two more principles:

> #4. Social interaction: Learning gains from patterns of social interaction that support the construction of knowledge and understanding.

> #5. Social distribution: What is learned and the thinking processes behind learning often are socially and physically distributed, features of the group and physical artifacts involved, not just of individual minds.

Situated and Generalized Learning

A growing community of scholars have come to view the process of learning as situated in particular contexts and the products of learning as highly contextualized. As to the former, "learning methods that are embedded in authentic situations are not merely useful; they are essential" (Brown, Collins, & Duguid, 1989, p. 37). Or as Resnick (1991, p. 4) puts it: "the social context in which cognitive activity takes place is an integral part of that activity, not just the surrounding context of it." Thus the cognitions that occur and lead to learning are inextricably bound up in the context of particular social and activity settings.

From this follows another precept: acquired knowledge is strongly connected with and specialized to its context of action. Thus "Learning and acting are interestingly indistinct, learning being continuous, life-long process resulting from acting in situations" (Brown, Collins, & Duguid, 1989, p. 33). Accordingly, knowledge tends to be contextually welded. Thus, Lave (1988) adamantly argues against the functionalist idea that the mind and its content are like a box of neutral decontextualized tools, ready for use in a variety of situations after which they are again stored away in memory. Rather, knowledge and skill differ from one situation to another; they are not really generalizable, amenable for decontextualization, and hence not available for transfer.

To an extent, research evidence supports this view. People in roles that call for highly developed skills of, say, making change commonly employ very effective strategies that bear little resemblance to the generalized algorithms of arithmetic taught in schools (Saxe, 1991). Studies of expertise have shown again and again that effective thinking in a domain depends on a very extensive knowledge base particular to the domain, whether it be playing chess, solving physics problems, or programming computers (Ericsson & Smith, 1991).

However, sometimes such results have been overweighed at the expense of indications that generality plays an important role in learning and thinking. For instance, general skills like reading plainly function as important mediators of learning in many domains, granted that one needs to tune reading skills to the particulars of a discipline. Some areas of knowledge, for instance many branches of mathematics or epistemology, function as tool domains applicable across a wide range of areas of inquiry. Thus we apply calculus to population growth and quantum physics. We apply epistemological criteria like disconfirmability to psychology and cosmology. Experts in a domain, when facing problems of an unconventional character, bring to bear more general strategies in tandem with their domain knowledge (Clement, 1991). And reasoning across many disciplines appears to be shaped by general "epistemic games," for instance the use of constraint systems as in Newton's laws or statistical forms of argument as in psychology, that are widely applied not only potentially but in actuality (Collins & Ferguson, 1993; Ohlsson, 1993).

One especially important kind of general knowledge is knowledge of how to learn. Some learners demonstrably are "expert novices," "expert learners," or "self-regulated learners," who know how to handle themselves as learners and make much more rapid progress (Bereiter & Scardamalia, 1993; Bruer, 1993). Effective self-regulation of oneself as a learner depends not only on learning strategies but on generalized beliefs and attitudes that yield positive postures toward oneself and targeted areas of knowledge. For example, some students view their abilities as fixed and achieving understanding as a matter of quickly catching on; these "entity learners" are likely to give up prematurely when encountering difficult concepts. At the opposite extreme are "incremental learners" who recognize that understanding of initially challenging concepts can be achieved by persistent effort that gradually builds up a comprehension of the whole (Cain & Dweck, 1989; Dweck & Bempechat, 1980; Dweck & Licht, 1980).

If people do sometimes arrive at abstract principles and apply them usefully in diverse contexts, under what conditions does this happen? The extensive research on transfer of learning shows that commonly transfer comes hard: Learners do not make the connections that they might. Salomon and Perkins (1989) offered an analysis of the conditions under which transfer does and does not occur, articulating two distinct mechanisms of transfer, the "low road" and the "high road." Low road transfer, a relatively unreflective process, happens when learners practice a body of knowledge and skill to near automaticity in a wide range of contexts. Subsequently, that body of knowledge and skill is easily triggered in new contexts that make similar demands. Basic reading skills are a good example, easily and automatically evoked whenever a learner picks up a beginning text on a new topic. High road transfer, in contrast, depends on effortful mindful abstraction from one context and application to others, as for instance in applying principles of statistical reasoning learned in psychology to phenomena in sports. While some aver that this rarely happens, Nisbett and colleagues (1993) offer evidence that it can easily be educed under the right conditions. Salomon and Perkins argue that transfer commonly fails because both high road and low road conditions are absent. Neither is likely to occur routinely by accident. However, when learning environments by design support low road or high road transfer, then transfer occurs.

In summary, it's fair to say that both the process of learning and what is learned tend to be highly situated within particular contexts and activities. When those contexts and activities are highly artificial, detached from contexts of application, and inattentive to problems of transfer, as happens all too often in school learning, the learning may suffice for the quiz while preparing students hardly at all for anything beyond the quiz. However, it is also true that general decontextualized knowledge commonly speaks to and empowers people in particular situations; and that people sometimes abstract from particular situations knowledge of a highly general character that they then find good uses for elsewhere. We can put these notions into three principles with a dialectical relationship:

> #6. Situated learning: Meaningful and effective knowledge tends to be highly tuned to its particular contexts of acquisition and application; effective learning therefore needs to

occur in social and activity settings that have some authenticity as settings of learning and as gauged by later potential applications.

#7. Generalized learning: Through processes of diverse practice or active abstraction, useful general knowledge can be drawn from particular contexts; through the triggering of well-practiced routines by pattern recognition and through active instantiation of principles, general knowledge can be usefully applied to particular contexts.

#8. Self-regulated learning: Knowledge, beliefs, and attitudes about learning itself can empower learners to organize their own learning much more effectively.

Knowledge networking

The eight principles foregrounded are not intended to be a complete catechism about learning. They by no means exhaust all that is important. For example, they do not explicitly address the importance of feedback in effective learning, a venerable principle of the behaviorists that proves equally important in contemporary perspectives. They do not pronounce the importance of motivation in learning, although making learning more situated, social, oriented toward understanding, and self-regulated are likely to enhance motivation greatly by enhancing relevance, intrinsic motivation, and like factors. Nonetheless, the eight provide an outline of several contemporary ideas about learning.

What kinds of learning experiences might honor these principles?

By their measure, an ideal learning experience would have such features as these:

* Active engagement to ensure the construction of knowledge.
* Activities that call for thinking in appropriate ways, such as connecting, gathering and selecting information, generating and testing hypotheses, generating inferences, to build understanding.
* Opportunity to explore a number of semantic relationships involving the target knowledge, to build a rich semantic network.

* Patterns of social interaction in the forms of teams and collaborative learning supporting the above.
* Responsibility for different aspects of the target knowledge distributed somewhat across different learners and supported by physical artifacts.
* The target knowledge imbedded in a social and activity setting rich in ways that foster the development of particularized adaptive knowledge and resonant with later potential applications. Some would call this an "authentic" setting.
* Learners both applying general knowledge they have to the social and activity setting and abstracting from it more general knowledge.
* Encouragement of attitudes, beliefs, and practices conducive to self-regulated learning.

This ensemble of features deserves a name to allow readier reference. We suggest "knowledge networking." While we are basically stipulating this term for convenience, it nonetheless has a certain resonance with the list of features. Knowledge networking reminds us of the active and thoughtful role of the learner, the semantic network that the learner needs to build, the social interactions involved and the distribution of knowledge across a social and physical network, the way that knowledge can be finely woven into the particularities of a situation and the way that links in a network can connect very different settings, in keeping with the ideas of abstraction and transfer. The notion of knowledge networking also puts learners in the drivers' seat, as the ones doing the networking with appropriate support from teachers and various resources, and positions them for self-regulated learning.

Of course, all the earmarks of knowledge networking need not show at every moment of a good learning process. Indeed it would be awkward, grotesque, and perhaps simply impossible to design such learning experiences. Nor does the above list litigate against segments of the learning process where relevant information is simply presented, as in a well-wrought lecture or textbook chapter. However, contemporary theory suggests that in the course of an extended learning experience around a topic, all the features of knowledge networking should have a strong presence, well orchestrated in a learning environment that manifests a <u>networking pedagogy</u>. Networking pedagogy would cultivate in learners not only knowledge, understanding, and transfer but also a range of skills and understandings related to regulating their own learning and managing knowledge.

Regrettably, networking pedagogy contrasts sharply with what one ordinarily finds in school settings (e.g. Bruer, 1983; Brown, 1991; Perkins, 1992). Conventional instruction tends to downplay thinking with the target knowledge in favor of more routine exercises, networks knowledge narrowly rather than broadly, constrains social interaction mostly to teacher-student exchanges, minimizes sharing and division of responsibility for building knowledge, foregrounds schoolbook contexts of problem solving that are not well situated in the discipline or its uses outside classrooms, and does little to cultivate self-regulated learning.

The role of technology

The notion of knowledge networking puts us in a good position to return to the role of information processing technologies. Of course, knowledge networking in principle does not require computers. Any of the features of knowledge networking can be pursued with some success in settings that employ no computers. The kinds of cognitive engagement highlighted can be sustained by pencil-and-paper problems and projects and group dialog. However, if as argued earlier, the needs of learning and not the power of computers should set directions for the use of computers in education, in which direction does the compass point?

At least two major directions for the educational employment of advanced information technology appear on the compass -- enabling the actual realization of the psychological conceptions and rationales presented above, and presenting new instructional possibilities (as well as pitfalls) requiring extensions and adjustments of the rationale. Basically, computers can become partners in cognition with learners, undertaking selected portions of the cognitive processing learners need to do and facilitating other portions in ways that foster higher order learning (Salomon, Perkins, & Globerson, 1991). In other words, computers rightly used can enable what needs to happen in knowledge networking. Computers can make easier and more efficient what might otherwise need to be done in more cumbersome and convoluted ways, or -- as in the case of constructing multimedia presentations, communicating with overseas peers, searching through archives, and through rich databases, or building dynamic models -- enable that which could not possibly be carried out in their absence.

For instance, computers and attendant resources such as CD-ROMs or network-accessible databases can provide quickly accessible, and efficiently searchable information resources. Through E-mail, computers can support a social network beyond the confines of the classroom. Collaborative activities among students with computer activities as the focus are a well-known pattern. Outliners and diagramming software allow for the direct overt expression of semantic networks that students are building -- and the effort to express them of course refines and extends them. Multimedia composition systems, and even conventional word processors, allow students to construct concrete expressions of ideas that have a real and meaningful audience in other students as well as the teacher and provide occasion and motivation for feedback and refinement. The thoughtful engagement required as students express concepts, offer viewpoints, build arguments, capture analogies, and so on, can advance their understanding as they think with what they know. In summary, in a number of ways computers might enable the kinds of cogitations and interactions called for by knowledge networking and the design of learning environments that foster these processes.

The catch is that a lot depends on the details. E-mail can be a channel for gossip as well as reflection. Multi-media composition systems can become a playground of special effects with little pertinence to the target knowledge. To repeat a refrain emphasized earlier, the technology of itself does not do the work of teaching, supportive as it may be. To see how computers can foster knowledge networking, we need to look to particular examples and discern how they tap the potentials and avoid the pitfalls.

Knowledge networking, as described above, calls for a different kind of learning environment which underlies what might be called a "networking pedagogy". Environments that reflect the networking conception and allow it to play out are varied, yet they share a number of basic attributes: Learning is real-life problem or issue driven, calling for genuine and purposeful knowledge construction and design, thus inviting understanding-performances and high level thinking; the generation, formulation, and posing of questions play a central role, thus shifting the focus from knowledge recitation to knowledge gathering, selecting, and arranging. The information collected for the solution of a problem or the design of some entity is very often multidisciplinary, affording the creation of understanding as networks of meaningful connections, as well as mindful ("high road") cross-domain transfer. It is a team and collaboration based process, with its joint appropriation of meaning, its opportunity for the sharing of other-regulated learning to become self-regulation, and its facilitation of the social distribution of thinking. And it is a process aided by a variety of high level technological tools for design, communication, information retrieval, and simulation, which enable the realization of a networking pedagogy while serving as the stage on which it can be usefully played out.

These features can be found nowadays in a number of pioneering projects which differ from each other in detail and emphasis but not in essence and rationale. Consider, for example, Bereiter and Scardamalia's Computer Supported Intentional Learning Environment (CSILE; e.g., Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). CSILE is a student-based, communally-generated database for early elementary students' play writing, and for the joint construction of databases on issues of ecology, biology, and other "thematic spaces" by children in higher grades. Students identify areas of inquiry and pursue them, reporting into the database, getting critiques, and pushing their investigations further. Technology is the set of means without which that kind of constructive activity would be impossible difficult.

The same features, differently arranged and with somewhat different emphases can be found in A. Brown and Campione's "community of learners" (e.g., Brown & Campione, 1994) in which teams of children jointly tackle a complex issue, jointly construct their particular expertise to be shared later on with other peers by way of the jigsaw method. Given the need for accessible and rich information sources, technology becomes an indispensable set of tools. The Vanderbilt projects of "anchored instruction" (The Cognition and Technology Group at Vanderbilt, 1992), manifested for example by the videodisk real-life mathematics problem driven set of team-based activities is yet another pertinent example of what we have come to call the networking pedagogy. The Jasper series emphasizes the cultivation of situated ("anchored") skills through the intensive employment of technology.

A project in Israel - "Sela" - is another relevant example. In that project eighth graders have to solve a real and interdisciplinary problem (e.g., what to do with a sunken nuclear submarine that leaks radiation; how to design an imaginary town free of current urban problems). This problem is then broken down by the students into team-based sub problems and specific questions (e.g., how to reach the submarine; how to solve traffic congestion problems in the future city) to be mindfully answered on the basis of carefully selected and studied information and communally shared by means of a team-designed multimedia presentation.

These cases illustrate the way instructional employments of technology become justified by a rationale that, as pointed out earlier, can be defended on psychological and pedagogical grounds that are technologically-independent. The justification for a new wardrobe is not based on the existence of a novel zipper, shinny as it might be. In the light of that rationale, one can see how essential technology becomes is aiding and often even determining the actual realization of that rationale.

But it is not only a case of making a pedagogical dream come true; often the dream is influenced by what the technology affords, thus leading to the modification of the rationale. Indeed, conceptions of the human mind become ignited by images of computers' flexibility in handling information. The easy access to vast bodies of information, libraries, data bases, archives, discussion groups, and bulletin boards, afforded by new technological developments, appears to affect our conceptions of knowledge. For if large bodies of information are so accessible, and if the manipulation of the information so gathered is so easy, may well be that the possession of knowledge stored in students' minds, as traditionally cherished and tested by school, is less valid today than in the past. March (1987) has argued that the real change in education will take place only when our conception of knowledge changes. Herbert Simon (1982) has suggested that such a change occurs once we come to perceive the concept of knowledge not as a noun denoting possession but as a verb denoting access: Knowledge as a process of access and manipulation, not as a matter of "having" or not "having" it. This conceptual shift, triggered as it is by new technological possibilities, has important ramifications for the rationale presented earlier: Technology as the tool for the realization of a rationale based on new psychological and pedagogical understandings as well as a trigger for the development of that rationale.

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