THE FUTURE OF COMPUTERS IN ENGINERING EDUCATION

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Introduction :

The area that stands to gain particularly from more computers is education. It is in education that the most promising market for future expansion lies. Using computers in education does not mean teaching about computers, but rather exploiting them to represent and communicate ideas within substantive academic disciplines. The central promise that computers hold for education, all of education, is the provision of a domin in which students don't have to take someone's word as to what happens. The first message in meta-learning is : you can do this stuff AS WELL AND BEAUTIFULLY as anyone else. The teachers must try to continually provide students with visually striking results, to reinforce this sense of well-being and control as the curriculum progresses.

The scenario

We see today that computers are proliferating in wealthy homes and wealthy private colleges, leaving the poor to become illiteratre. Back in the days of mainframe computers, one needed either great expertise or great wealth to get access to a computer. With the era of microcomputers, there are a lot of machines around and lot more will be made available in the future. One doesn't need much more than desire. Anyone who genuinely wants to, can get access to computing power to get more familiarity with computers than ever I managed.

However, there is one skill that is prerequisite to nearly everthing. The real problem with our educational system is that a great number of students get out of school without learning any kind of literacy. I submit that illiteracy in English is far more damaging than computer illitercy - and a school system that can't teach students how to read and write isn't likely to have significant success in teaching them to use computers. Even though we have Christian as one of the religions of India, we are out to deprive our pupils of the study of English - the language of the Christian, that we have religiously learned in order to acquire the knowledge of modern science and technology, during the long rule of the British on our country. To me, the best way to see that the next generation has computer skills is to see that everyone aspiring for engineering career has competency in English, in addition to other Indian languages.

The three R's

Reading, w(Riting), and (a)Rithmetic - are the three R's. As educators, it is important that we understand the three R's. As com-

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puter educators, it is important that we understand how computers interface with and possibly affect the three R's. But we become so enamoured with computer potentials that we forget why the BASICS are so named.

Reading provides access to information, A book is an inexpensive, easily portable vehicle for transmitting large quantities of information over time and distance. Reading provides access to quite a bit of the accumulated knowledge of the human race. Reading is also a form of entertainment. Writing provides the materials to be read. Equally important, writing is an aid to the human mind as it works to solve a variety of problems. For example, writing provides temporary storage of ideas as we work out the order and details of a plan. Arithmetic also serves two major purposes. Numbers can represent quantity or location, distance, time, area, volume, and other measurements. Arithmetic (more generally mathematics) provides a language to represent, store and access these types of information. As with reading and writing access these types of information. As with reading and writing, quantifiable information can be transmitted over time and distance. Geometric theorems of Euclid are as valid today as they were two thousand years ago. Arithmetic is also an aid in problem-solving. If a problem can be represented using the notation and ideas of arithmetic, then one may be able to solve the problem using the accumulated knowledge and the tools of this field. The tools include operations such as addition, subtraction, multiplication and division; other tools include drawing diagrams and graphs.

Tools for increasing the power of the three R's

Reading and writing are very important media in communications. A number of tools like telegraph, telephone, photographs, movies, radio, television, phonographs, tape recorders, leser discs and computers - all aid communication over time and distance. Each new invention of a tool broadens the scope of communications. It may take substantial training and experience to develop a tool. The requirement of marginal skill in using new inventions is the result of the development of appropriate user-machine interfaces. We experience this in modern cameras and television sets. On the other hand, some inventions actually decrease or substantially change the type of experience important to the acquisition of the three R's. The typewriter has reduced the relative importance of being able to write very neatly and speedily. Even a novice can learn to type, thereby rapidly acquiring useful skills. The three R's are aids in organising our ideas. A word processor can be useful in taking notes in the class, but it can never replace pencil and paper for doodling during an incomprehensible lecture or a dull discussion session. Moreover, pencil and paper remain and excellent tool for prewriting and other organising processes. Simliarly, a calculator can aid in number mainpulations, a computer can aid in symbol mainpulations, solving complicated equations or simulating a behaviour. But the effective use of these tools will require mastery over the vocabulary, notation and methods presenting the problem using the computer. In this case also, no computerised system approaches pencil and paper as an aid in organizing one's thoughts and trying to figure out how to define or solve an engineering problem.

Thus, computers do not decrease the value of the three R's. However, they are an aid to accomplish the underlying purpose of each of the three R's. Thus the ready availabiltiy of the computers actually tends to broaden the scope or nature of each of the basics and thus places an additional burden on our educational system somewhat. Gradually, computers will be assimilated into the definition of each of three basics. Even-

tually WRITING will include the use of a wordprocessor, READING will include accessing information from computerised detabanks, ARITHEMETIC will include making use of calculators and computers as aids to problem-solving and BASICS WILL STAY BASICS.

The impact of media

We live in media as fish live in water, seeing and dealing with them but not recognizing their effects on our life and on our thinking. Television made its entry in the western world in the late forties. By being vivid, passive, and narcotically habit- forming, it is beginning to shape our lives as well. It is bringing a decline in literacy, in vocabulary, in mental awareness, and in our ability to read diagrams and tables. As Marshall McLuhan uncannily forsaw ir for USA, our nation has also likewise re-entered a sort of TRIBAL state in which mind can no longer grasp specifics, rejects them like transplanted organs, and deals with the world instead on the basis of tinely-tuned intuitions - whose vocabulary is brilliantly played on by commercials and the so-called news. Those of us who came from a gerantion of words and literacy think this is very bad, and hope the tide of dementalization canbe reversed. Now we are a new time and HUNDREDS of new media are being impatiently prepared by lunatic dreamers and corporate teams everywhere. The exact details of the new media matter enormously, and we are indeed in danger that very bad ones will be adopted, enveloping us irrevocably in systems that will cripple our thinking and our access to information in more ways than television has, cutting us even further from analysis, from facts, from access to the past, from clarity and from intercomparision. Yet there remains the very real hope of that unified canopy of vivid and accessible information, an environment which well enhance and nourish literacy but far beyond, to new levels of understanidng and intelligence. This is a difficult message to propound, since many may fell threatened by the idea that the next gernation will be smarter - the same anticipatory resentment that often leads present unconsciously to hold their children back. But tomorrow needs all the human intelligence that can be created, through every possible mechanism and channel.

Media in engineering education :

In any media, written, visual, filmic or whatever, you generate instantaneously an atmosphere, a patina, a miasma of style, involvement, personality (perhaps implicit), outlook, portent. Next to this mater of mood, all else pales; the actual constraints and structers of media; the expositions and complications of particular cognitive words and representations within media, are nothing.

Time after time, the educational establishment has thought some great revolution would come through getting new kind of equipment into the classroom. First was movies. More recently it's been AUDIO-VISUAL stuff, teaching machines, film loops and Computer- Assisted--Instruction (CAI). In no cases have the enthusiasts for these systems seen how the equipment would fit into conventional education - or more likely, screw the teacher up. Teachers are embarassed and flustered when they have to monkely with equipment in addition to everything else. Even the existing applications software for word-processing, spreadsheets and database management is not so much user-friendly. As a consequence of this, our teachers continually apologize for their lack of expertise; they are continually made to feel inadequate.

The only real possibilities for change lie in systems that will change the instructor's position from a manager to a helper. Many

teacher will like this, many will not. As far as the teachers are concerned, no major subject in their curriculum is less than 50 years old, and most of the content in the subjects is hundreds of years old. On the contrary, for computers, almost everything is less than 50 years old and much of it is less than a couple of years old. Computers are both a relevent aid to problem-solving and a source of problems in every academic discipline at every academic level.

The dream machine by theodor nelson

We need a type of hardware with user interfaces which are, in some measure, intuitive; emulating through software, the way we think, and which gives at least the illusion of total control in our hands. This approach is feasible and was proposed as back as in 1973 by Ted Nelson in his book THE DREAM MACHINE.

Hypertext

According to Ted, perhaps the most tragic aspect of software today is its shallowness. The computer people are abandoning the most important possiblities of the interactive computer screen. People are SIMULATING PAPER on the screen. Designers are sticking to systems where printout is imagined to be the final proper version and even these systems rarely get out of the first gear. Ted called his new forms of multidimensional documents for computer screens as HYPERTEXT. By hypertext, he meant non- sequential writing. Ordinary writing is sequential for two reasons. First, it grew out of speech and speech-making, which have to be sequential; and second, because books are not convenient to read, except in a sequence. But the STRUCTURES OF IDEAS are not sequential. They tie together every-which way. And when we write, we are always trying to tie things together in non-sequential ways. Thus we have been speaking HYPERTEXT all our lives and were never aware of it. But now with computers under our command, a new day is dawning. Computer storage and screen display mean that we no longer HAVE TO have things in sequence; totally arbitrary structures are possible; and after we have tried them enough, people will see how desirable they are. Ted first published the term HYPERTEXT in 1965. For twenty years he gave speeches and wrote articles about how we need hypertext for edcuation, scholarship, archiving and the OFFICE OF THE FUTURE - not to mention poetry. The idea caught in 1986 because of Note Cards programme from Xerox PARC (Paulo Alto Reseach Center), Gary Kildall's (originator of the operating system CP/M) mention of hypertext in the 1986 CD/ROM conference, the GUIDE hypetext programme from Owl in Seattle, and the project of the Hypertext Abstract Machine (HAM) at Tektronix.

Why hypertext

The notion of SEQUENTIAL PRESENTATION is deep in our thinking. The TV show, The movie, the fairy tales, are sequential. The REPORT TO MANAGEMENT is sequential. People keep pretending they can make things hierarchial, categorizable and sequential when they can't. In an important sense, there are no SUBJECTS at all; there is all knowledge, since the cross-connections among the myriad topics of this world simply cannot be divided up neatly. Hypertext offers the possiblity of representing and exploring it all without carving it up destructively. The very same field of knowledge that others represent as an explorable, formalised whole, Ted represents it as an explorable, INFORMALIZED whole, with anecdotes, jokes, cartoons, ENRICHMENT MATERIALS, and anything else people might dig. Hypertext, thus consists of EVERYTHING written about a subject, or vaguely related to it, tied together by editors -- and NOT by programmers -- in which we may read IN ALL THE

DIRECTIONS WE MAY WISH TO PURSUE. There can be alternative pathways for people who think different ways. There might be some people who HAVE to have one thing explained to them at a time; while others, learning like true human beings, may gather and sift impresslions until the ideas become clear. And then, of course, we see the real dream _- the dream of GRAND HYPERTEXT -- the real dream for EVERTHING to be in the hypertext.

Now that we have all the wonderful devices, it should be the goal of society to put them in the service of truth and learning. Now we need to get everybody together again. We want to go to the roots of our civilization -- the ability which we once had, for eveybody who could read to be able to read everthing. We must once again become a community of common access to a shared heritage. Hypertext retains and puts back together the great traditions of literature and scholarship, traditions based on the fact that dividing things up arbitrarity just generally doesn't work. EVERTHING IS DEEPLY INTER-TWINGLED. All structures must be treated as totally arbitrary, and the hierarchies we find are interesting accidents. Hypertexts were foreseen very clearly in 1945 by Vannevar Bush, Roosevelt's science adviser. When the war was in the bag, he published a little article, AS WE MAY THINK, on many groovy things that had become possible by that time.

Danny hillis, the architect of the hypercube computer :

As a line is the extension of a point in the next dimension, a square is an extension of a line in the next dimension. A cude is the extension of square in the NEXT dimension. And after that -- can it go in OTHER DIMENSIONS? Sure. DIMENSION simply means YET ANOTHER DIRECTION AT RIGHT ANGLES TO THE OHTERS. We can always add a dimension whenever we want to breanch out in one more direction of anything. A hypercube is thus the extension of a cube in a direction at right angles to the directions of the earlier cube. Thus a hypercube computer consists of lots of processors whose interconnections are in the form of a hypercube. Each processor is able to communicate or share memory with those connected every wlhichwise. One extraordinary young dreamer, Danny Hillis, has put a real punch into the theroy. At Thinking Machines, Inc., in Cambrige, Messachussetts State in the USA, Danny Hillis, Marvin Minsky's former right hand wit has built the Connection Machine, a multicomputer of immense power. The separate computers are not very powerful, but EVERY ONE IS CONNECTED TO EVERY OTHER, leading to extraordinary new powers and the darn thing WORKS. with over SIXTY FOUR THOUSAND little computers, all interconnected, each as powerful as (say) an Apple II, the Connection Machine is already the most powerful computer in the world. It is the first REAL depreature from classic computer architecture. It looks as if Danny ranks with Babbage, Mauchly, Cray, Noyce and Bell as one of the great computer designer. But wait, Danny is talking a million dimensions. And noe people take him seriously.

Hypertext in the classroom

The hypertext approach does not confer omniscience or omnipotence upon the author teacher. The writing, like all writing, represents a point of view. As with paper, the author cannot imprison the student or make insuperable requirements. Any non- sequential text, through a Hypertext portal, confers on the student this freedom. A principal point is that the student is in control and his intiative dynamically; the subject is not artificially processed into a presentational sequence. Moreover, the arbitrary interconnections of the subject, which are no respecters of the printed page, are recognized as the fun-

damental structures the student must deal with and come to understand. The sense of initiative makes all the difference, and hypertext promotes that.

Object-oriented language

In an object-oriented language, your pieces of programme and data behave more like pieces information. An object responds to messages that are sent to it by other objects, and each object has a vocabulary of messages it is prepared to send and receive. Programmes and data structures are both packaged as OBJECTS, named chunks that enumerate ALL THE THINGS THEY CAN DO - the METHODS, or programs they can use, and the outside MESSAGES that will trigger them. AN OBJECT is like a package that describes a specific kind of data and the set of all procedures that may work on the data. Thus an object is a higher-level grouping of informations; a type of package specifically designed for modularity and flexibility.

Ted calls SMALLTALK as the best-known object language that is legendary and widely misunderstood. At Xerox PARC (Paulo Alto Research Center) Alan Kay developed Smalltalk to be a complete development environment. The Smalltalk environment pioneered the concept of dispalying different tasks in multiple windows on a scren. Using a mouse for screen interaction is another Smalltalk innovation. Smalltalk bridges the gap between human and computer problem-solving logic. Essentially, programming is the process of creating a model of an activity of thought process. In traditional programming languages, a small change in a problem can require a large change in the program code (owing to the languages firm bases in machine representation). And many languages involve special, often particularistic sets of skills. Higher level programming languages are simply higher level abstractions from machine logic. Smalltalk, on the other hand, starts with an object-oriented model of problem-solving logic and deals with the machine logic internally and automatically. Where other languages need guiding constructs like STRUCTURED PROGRAMMING to help control the complexity of machine representation, Smalltalk proceeds along more natural intuitive lines. And, as the needs of the Smalltalk user change, applications are easy to modify and maintain.

Impact of information technologies on students and teachers

Unlike other necessities of life, information technologies are rapidly increasing in power while dropping in price. Numerous emerging hardware developments have implications on educational technologies. The next generation of information technologies will synthesize the attributes of computers and telecommunications. Devices will emerge to combine the capabilities of telephone, television, radio, printing press, computer and copier. Already, real-time digitization and storage of high reso;ution images (30 frames per second) are available for personal computers. However, all this power has little meaning unless software takes advantage of its capabilities. Fortunately, simultaneous with these hardware advances, our understanding of the potential of computers has expanded from number crunching to data processing to symbol manipulation. New types of applications have been created as our conceptions have become more sophisticated and as the power to support more advanced functions has become available.

Cognition enhancer software

Instructional usage of computers has evolved through different stages: from computer literacy to programming languages, computer assisted instruction (CAI), and computers as tools (e.g. word procesors

databases, spreadsheets, graphics). Researchers in artificial intelligence and congnitive science are now developing intelligent tutoring systems and cognition enhancer software. In such a software, cognitive strengths of a person and an information technology can be used in partnership. Computers have large short-term memories (megabytes of RAM), while human beings are limited to an immediate storage capacity of less than 10 chunks of information. Computers can execute complex ALGORITHMS (precise recipes for sovling one clas of problem) more rapidly than people. For tasks involving manipulation of successive symbolic results like those involved in mathematical or numeric methods, these cognitive attributes give computers an advantages over humans. The superiority of computers in standardized problem solving has therefore to be exploited by people. On the other hand, people store information over the long term in rich SEMANTIC NETWORKS containing webs of associiationally related textual, temporal, and visual imagery. The cognitive attributes of human beings give them an advantage over computers at applying peripheral real-world knowledge to ill-structured problems (like diagnosing the source of student's motivational difficulties). People are still much better than computers at problem recognition,at metacognition (thinking about thinking), and at non-standardized problem solving. Researchers are working to develop intelligent devices which could teach a student a particular topic without the help of a human instructor. A machine-based tutor could show a pupil the steps to follow in simulation, guide the student through examples, give sample problems to test comprehension, diagnose errors, and provide remedial instruction. A computerised coach could monitor a pupil engaged in problem solving, looking for patterns of suboptimal moves and occasionally intervening to suggest a better strategy. This mirrors the one-on-one instruction a human teacher could provide. However, because of current limitations of computers, cognitive science, and artificial intelligence, developing devices capable of independent instruction is difficult. While intellignet machine-based tutors and coaches will gradually become useful in educational settings, cognition enhancers designed to combine the cognitive strenghts of humans and computers will evolve much more rapidly. These tools are still in their infancy, but so far, three kinds seem to be emerging: empowering environments, hypermedia, and virtuality.

Design issues in empowering environments

This type of cognition enhancer uses the computer's strengths in structured symbolic manipulation to empower human accomplishment through a division of labour: the machine handling the routine mechanics of a task while the person is immersed in its higher order meanings. In designing this type of cognition enhancer, the first design issue is of rich comprehension of a domain to generate an optional menu of manipulable symbols and processes for the user. The second type of design issue concerns with the range of tasks like a MYTH CONSTRUCTION SET, for which empowering environments would be useful. Similar elements underline the myths in all disciplines, and many disciplines have closely related myth structures. An empowering environment might be useful for building, comparing and tailoring a technological myths, just as a word processor allows the manipulation of words and word structures. The third design issue concerns the capabilities of the empowering environments. Intelligent coaches with embedded models of expertise could monitor a user's work, intervening to improve patterns of suboptimal performance. Similarly, empowering environments could save COGNITIVE AUDIT TRAILS of user operations so that the sequence of operations

could be reviewed by the user later for patterns of errors and ways to enhance the performance. Consciousness sensors which monitors the user's motivation and mood through tracking respiration, skin conductivity, heart rate, and other physiological measures present another possibility. Primitive empowering environments are beginning to be used in education. A word processor with spelling checker, thesaurus, typing tutor, and graphics tool is the beginning of an empowering environment for writing. Even the elementary versions of this kind of cognition enhancer have an interesting property: their usage unconsciously alters the STYLE of task performance of the user. In a world of intelligent empowering environments, the ways we accomplish many tasks may undergo a change.

Hypermedia

In recent years, a very basic change has occured in presentational systems of all kinds. We may summarize it under the name BRANCHING, although there are many variants. Essentially, today's systems of presenting pictures, texts and whatnot, can bring you different things automatically, depending on what you do. Selection of this type is generally called BRANCHING. Ted has coined the generic term HYPERMEDIA for presentational media which perform this (and other) multidimentional ways. A number of branching media exist or are possible: Branching movies or HYPERFILMS, Branching texts or HYPERTEXTS, Branching audio, music, Branching slide shows etc.

Hypermedia is a framework for nonlinear representation of symbols (text, graphics, images, software code) in the computer. Long-term human memory is seen to be a storage system of associational semantic networks; we Know everything we want to write, but not have our ideas in the linear stream required for oral or written communication. We need an IDEA PROCESSOR, a way of externally creating a multi-dimensional construct which mirrors the concepts and links, forming the material in our memory. With our knowledge externalised into a hypermedia system, we can travers this network a long alternative paths through nodes and links, seeking the right sequential stream for our intended content, audience, and goals. The computer works in cognitive partnership to eliminate the overload involved in transfering long-term to short-term memory may be enhanced by the process of building and using hypermedia. Hypermedia is a general tool that can be utilized in several different ways. In addition to serving as an externalized associational memory for an individual, hypermedia could be an alternative reprresentational system for a large, shared database. Such an approach would encourage group interdisciplinary exploration by explicitly interconnecting similar ideas in different subjects. Hypermedia as a Knowledge representation format empowers instructional design based on cognitive principles of learning such as active structional design based on cognitive principles of learning suchnas learning. AN INFERENCE ENGINE, which is a component of an expert system that supports reasoning about data, can be built onto a hypermedia framework. Some software systems use a TRUTH MAINTENANCE SYSTEM to propagate changes made in one part of the code into their consequent impacts on other sections of the program and documentation. In this way, the system forces the user to examine all the consequences of altering one part of the code. The emergence of primitive hypermedia systems on personal computers is likely to unleash a variety of new ideas about uses of cognition enhancers. These ideas might enhance our comprehension over the forced linearity of textual presentations. Perhaps new styles of remembering and knowledge transfer will involve as well!

Virtuality

Everyone knows what is real, more or less. it is the physical, the tangible, the measurable. In computerdom, there is a word which is opposite of REAL. That word is VIRTUAL. It means AS-IF. A VIRTUAL FILE is something which is not stored as a file, but behaves as if it were a file. A VIRTUAL DISK is something which is not a disk, but behaves as if it were a disk. So Ted proposed the term VIRTUALITY for the way things SEEM TO BE, as distinct from how they REALLY ARE. What Ted calls this type of cognition enhancer VIRTUALITY, is approximately what Seymour Papert calls a MICROWORLD and what Myron Krueger calls an ARTIFICIAL REALITY. In a movie, you probably can't tell whether a certain scence was shot in a real room or a painted set, whether it was shot in a studio or on a location. These are REALITIES, and they are of no concern when enjoying (or evaluating) the movie. In terms of the movie's impact, the important thing is that THE SCENE TAKES PLACE IN A CERTAIN KIND OF ROOM. That is the virtuality. The virtuality is a construction that may be quite independent of its underlying materials; it is a MENTAL CONSTRUCT.

Virtuality Vs Metaphor

There is a lot of talk lately about METAPHORS in interactive design, meaning resemblances or analogies that are conceptually useful. For example, screen widnows are called metaphors. A collection of screen windows resembles a desktop -- the DESKTOP METAPHOR. Spreadsheets are called metaphors. A spreadsheet on a screen resembles a paper spreadsheet. But the notion of VIRTUALITY is much more general; a virtuality need not resemble anything; its conceptual structure and feel need only be tuned as the designer sees fit, in any direction. The problem is of DESIGNING IDEAS. The ideas someone will be working with on the computer can have any shape at all; their arbitrariness is mind- boggling. So the problem is carefully balancing and adjusting the ideas into a smooth whole, making these adjustments in whatever directions seem best. The real issue in computer systems, as in movies and art, is THE DESIGN OF VIRTUALITY : imagining, and carrying out, a detailed overall structure that conveys both an intended CONCEPTUAL STRUCTURE and an intended FEEL to the user. This is the central issue. Good interactive design does not select metaphors, or figure out INTERFACES, or start with tools and work upward. Good interactive design is concerned with the overall structure of the virtuality presented to, and experienced by, the user : getting a conceptual structure across clearly, with an integrated feel that promotes continual understanding and fluent usage.

Virtuality allows the user to explore and manipulate limited artificial realities. A problem that lcarners constantly experience is how to relate abstract, formal knowledge to specific real-world situations. What we need is virtuality in which we can vary the conditions to observe the fundamental properties like gravity. The students could use the computer to explore the activity of a cricket ball at earth's gravity; then at the moon's gravity; then Jupiter's gravity; even a very short game at zero gravity! Varying one item at a time, we could work through the constants and variables in the gravitational equations, altering each in turn to see how the game of cricket could change. Then students would have both formal and applied knowledge of the theories underlying gravity.

Impact of cognition enhancers on the classrooms of tomorrow

Science and fiction writer Isaac Aimov once said that the important thing to forecast is not the automobile, but the parking problem; not the incometax, but the expense ac-

count; not the television, but the soap opera. Similarly, the fundamental issue is not how many empowering environments, hypermedia systems, and virtual systems will be in the classrooms in a decade, but how they will change the relationship between student and teacher, school and society. Christopher Dede has illustrated potential impacts of a widespread, long-term usage of cognition enhancers :

New definition of human intelligence

New strengths in partnership between people and cognition enhancers involve skills such as creativity, flexibility, decision making in an environment of incomplete data, complex pattern recognition, information evaluation/synthesis, and holistic thinking. Such higher order mental attributes might become a new definition of human intelligence, as basic cognitive skills would increasingly shift to the use of intelligent tools. Polishing student's mastery of lower-level skills would be like grooming John Henry to complete with the steam engine!

Goal of teaching the three R's

Students would still need fundamental descriptive and procedural knowledge - one cannot master higher-order skills without foundation of lower-order concepts and processes - but the goal of teaching the basics would shift from performance fluency to providing a cognitive underpinning for sophisticated problem recognition and unusual problem solving. Methods of educational assessment would alter from charting mastery of descriptive knowledge to evaluating attainment of higher-order skills. Cognition enhancers shall aid in collecting the detailed individual data necessary, as well as empowering more sophisticated empirical educational research.

Learning while doing

This would become a significant component of education since combined technologies of computer and telecommunications make decentralized instructional service possible. To allow credit for occupational accomplishments, workplace tools may include intelligent devices that act as job performance aids while simultaneously collecting a cognitive audit trail of user skill improvements, creating increasingly informal systems of credentialization. Occupational roles will alter rapidly as the evolution of information technologies drives the knowledge-based economy, and adults may become major clientele of schools.

Coordination of educational components of society

Widespread use of cognition enhancers would facilitate the participation of every person associated with the educational process - learner, teacher, administrator, employer or parent - in shaping instructional outcomes. Society's five primary agents of education - schools, family, community, media and workplace - could act in a more coordinated fashion to shape the learning environments of individuals through the use of interlinked educational information utilities which provide access to a variety of data, courseware, tools and training.

Productivity gains

Productivity gains from a mature, technology-intensive educational approach could enable a higher overall ratio of students to teachers, but smaller class-sizes through supplementary use of intelligent technologies and non-school instructional media. Teacher salaries would be better and the total educational force might increase due to a wider range of clients. Given equivalent ex-

penditures, instructional outcomes would be significantly higher.

Development of personality and social skills

On the long run, the effects of intelligent technologies on cognitive style, personality and social skills may be profound. The television and the computer have each demonstrated the capability to shape the attributes of youngsters immersed in their usage. A technology-intensive model could incorporate interactive learning situations designed to build the effective skills of cooperation, compromise, and group decision making essential in a knowledge-based economy. The deliberate tailoring of individualized, information-intensive environments could produce a generation radically different in its characteristics from any previous one.

Enhancement of educational equity

Educational equity would increase through the power of intelligent systems to individualize instruction. Because the economic strength of a knowledge-based democracy is dependent on universally excellent persormance by workers and citizens, each member of society would have a strong self-interest in promoting optimal educational achievement by all learners.

Conclusion

the potential implications for civilization of intelligent educational environments could be profound. The next generation of information technologies could become history's first KNOWLEDGE MEDIUM : humanity's conscious mechanism for tailoring its cognitive evolution. Education would be a crucial component in a society's attempt to increase knowledge and wisdom through intelligent tools which aid in collecting, filtering, modelling and sharing of massive amounts of data and information.

To accomplish such a transformation, Dede emphasizes the need to overcome two myths in instructional computing. The MYTH OF POWER states that novices need less powerful devices than expert users. Dede argues the opposite : Rapid computational speed and large amounts of memory are required to support the self-explicating interfaces, multiple mental models, and alternative knowledge representations helpful to beginners. The MYTH OF CONSOLIDATION states that the wave of innovation in instructional computing is over : that we know what computers can do for students and, based on this summative evaluation, we can tailor our educational investments to more of the same machines, software, and teacher training. Dede argues the opposite : Much more powerful tools are emerging, attempts to judge how computers can improve learning are premature, and the real wave of technological change in schools is just beginning. Far from consolidation, we are just at the beggining of our exploration into education, cognition, and computation. The educators of the Information Age must see the tools and systems they create as a form of communication with others, as part of an interaction with users who are trying to understand and expand their capabilities.

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