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Developing applied critical thinking skills in students seems the most effective and efficient use of current and future computer technology.

Critical Thinking and Microcomputers: Education's New Tools for the Information Age

by Thomas McCahon

Since the widespread introduction of microcomputers into the public schools approximately three years ago, there has been considerable controversy over how and if computers should be used in the classroom. The issue of whether computers should be used in the classrooms is a moot point, since there are considerably more advocates than opponents to their introduction into education. The only question that needs to be addressed presently, is **how** are educators going to effectively and efficiently use this new technology? While the lure of the computer monitor is a great asset to educators in holding a student's attention, merely placing computers in the classroom and advocating their usage does not make students proficient or even functional citizens of the information/computer age.

Public education's primary technological dilemma has been a lack of direction in establishing educational criteria and priorities for the classroom use of computers. If microcomputers are in the classroom to stay, and it seems they are, there needs to be a different approach taken to the process of education, as well as a rethinking of what constitutes a "good" education. What may have been important in the classroom yesterday during the industrial age, is not as important during the computer age. Society's concepts about education are changing. It is no longer sufficient for students to merely be informed about technological and scientific changes in society, but they also must be able to function within those changes.

To make the transition into a process-oriented society, educators will need to endow students with reasoning skills that will be functional, regardless of the chosen profession. The ability to digest, analyze, and assess computer output, or think critically, becomes a necessary basic skill in the information age, much like reading. This fact has

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brought some educators to the realization that students will not be able to adequately function in the computer age without thinking skills that transcend linear or sequential reasoning ability.

There at once arises obstacles that must first be overcome if critical thinking skills are to be introduced into the classroom. Two of the more important issues facing the introduction of critical thinking into the classroom are teacher training and societal acceptance. It is essential that teachers learn to develop critical thinking skills and be able to pass those skills on to students through the curriculum. The instruction of teachers in critical thinking will necessitate a change at colleges of education. Secondly, critical thinking raises social and philosophical questions over whether society can fully adjust to the concept of a well-reasoned populace, though this has always been the goal of education.

What is Critical Thinking?

Prior to advocating the introduction of critical thinking into the educational process, there must first be an agreed upon definition of what constitutes critical thinking. Many definitions of critical thinking are continuously being formulated by educators, but most agree, at least tentatively, that it is the ability to produce dependable observations, generate reliable inferences, and present rational hypotheses. This definition in no way addresses all the necessary reasoning skills needed for one to become a critical thinker, but it provides a foundation. Critical thinking can be divided into two separate skills categories: simple and complex reasoning skills.

Thinking skills currently used in the classroom are of the simple type. Simple reasoning skills are essentially sequential or linear, and seek solitary or unique solutions to given problems. Solutions in simple reasoning are generally restricted by constraints, or boundaries of a solution space, specified in the problem. Deductive reasoning, analytical reasoning, logical reasoning, and cause-effect relationship activities are examples of simple reasoning skills. Such thinking processes tend to be rigid and do not allow for interactive factors or probabilities. This manner of thinking offers limited solutions to potential problems, but is central to most empirical research. Simple reasoning skills are used in practically all mathematics or science-related courses.

Complex reasoning skills are those that are currently beginning to receive more attention with the introduction of microcomputers into the classroom, but they are not new. Moreover, complex skills are what distinguish the successful thinker from the individual who is limited by linear thinking processes, which restrict one's decision making ability. Successful thinkers are persons who can observe without preconceived bias, and see numerous solutions to a problem where most can only see one. The versatility of the microcomputer, especially in graphic simulations, allows for the introduction of experimentation, creation, and evaluation of more complex problem structures that offer more than one problem solution. Complex reasoning skills are inductive and intuitive reasoning, synthesized reasoning, and recognition of interactive relationships in observations. These complex reasoning skills are found in some of the better algorithmically based programs, but they are more characteristic of heuristic-based software. Complex skills have often been neglected in the classroom in favor of the more common simple reasoning skills. Computers are beginning to expand from algorithms, which give unique solutions, to heuristic structures, which give numerous possibilities of solutions for problem-solving. Software based on

algorithms can only grow so large before it becomes impractical. By amassing larger data structures to offer more flexibility in applications and problem solutions, algorithmically based systems will inevitably slow computer response time. This limitation of application and growth potential is also true of individuals who use only the simple reasoning skills presently found in the classroom. While heuristics do not guarantee an empirically verifiable solution, they offer the potential for a multiplicity of solutions based on different approaches to a single problem. Heuristics also offer a wider diversity for application, by not being completely restricted to subjects that require a rigorously mathematical algorithmic structure.

Why do We Need Critical Thinking?

One of the fundamental omissions of public education today is the formulation of curriculums that develop problem-solving skills in the students. This failure becomes more critical and apparent as our society becomes more technologically complex and change or innovations continue to occur at their current rapid pace. With such a "knowledge explosion", schools in the future will not possibly be able to deliver all the important information that a student will need to adequately function in a complex technocracy. Information overload is a certainty in the computer/information age. Schools are going to be forced to start developing curriculums that stress process rather than product. Therefore, it becomes increasingly important that a student be able to independently research, digest, and evaluate information through a process of developed critical thinking. The current mindset of educators must be redirected toward developing reasoning skills in students, which will ultimately offer lifetime application.

Developed critical thinking skills, if introduced in the schools, can provide students with skills that are universally applicable, regardless of trade or profession. Some educators may assert that such skills are currently found in mathematics, grammar, and basic logic. Mathematics, logic, and grammar structures as they are currently being taught supply the student with simple reasoning skills, and only occasionally address the more complex skills.

The Implementation of Critical Thinking

Presently, many proponents of critical thinking advocate its introduction into the schools as a separate course, apart from other subjects. These critical thinking courses are generally based on learning logic, and such classes have been initiated in some public schools. This hurried introduction of logic into the curriculum is a response to parental pressure over various reports bemoaning the lack of problem-solving skills in public school students. While logic is an important precursive stage in critical thinking development, many educators invariably underestimate or neglect the importance of foundational knowledge used in structuring and supporting logical statements. Logic cannot assist the student in the formulation of a hypothesis or theory, but logic can lead to an eventual justification of that hypothesis or theory (McPeck, 1981).

There are many developmental stages to traverse in the educational process before true critical thinking is developed in a student. Every developmental stage has its own associated skills, which build upon previously learned facts and skills and can eventually produce the independent critical thinker. One of the essential elements in the critical thinking process is the ability to draw inferences. The need for such an ability as inferential thought means that critical thinking cannot effectively take place with any consistency

prior to the formal stage of a student's development.

It is worth noting that many advocates of critical thinking use Piaget's developmental learning theory for determining the implementation of critical thinking skills. The formulation of thinking skills coupled with the introduction of microcomputers in keeping with Piaget's theory have been instituted statewide in Oregon and California. The primary factor that educators must consider when implementing critical thinking skills at any grade level, is the knowledge base of the student. A student must have some knowledge of the subject before they can think critically about that subject (Mcpeck, 1981). Thinking cannot take place in a vacuum.

The Impact of Computers on Critical Thinking

The microcomputers' strongest asset is its problem-solving capabilities. Utilizing this asset to teach students to think critically seems a far more effective application of current technology than is presently in use. Present usage of the microcomputer is merely an extension of rote learning to another medium, the "electronic flashcard" monitor. While the microcomputer is not a necessity for teaching critical thinking, it can be an enhancement to the process.

Currently, microcomputers are being used to develop some foundational skills necessary for problem-solving, such as basic logic statements in computer programming, but not critical thinking specifically. Some educators believe that by having computers in the classroom, critical thinking will spontaneously develop out of student interaction with the machine. This may be true with some strong spatially oriented students, but not with the majority.

There is some similarity between the processes of critical thinking and computers which makes computer-aided critical thinking instruction a viable alternative. The similarity of computer processing and critical thinking can be observed in algorithmic processes, which parallels simple reasoning, and also in heuristic-based expert systems which resemble intuitive thought. This linkage of critical thinking and computers is especially strengthened by the advent of expert systems on microcomputers. Expert systems utilize heuristics which incorporate models that allow for more complex reasoning skills found in critical thinkers.

Software for Critical Thinking

The only present limitation with the microcomputer and its application to critical thinking instruction is software availability. Most educational software is drill and practice oriented. A notable exception to the drill and practice software, is Seymour Papert's LOGO for children. LOGO is supposed to help develop younger children's thinking skills, but its success is still open to question. However, there exists other software currently available on the market, which could be used or adapted to teaching critical thinking skills; it is game software. This does not include the mediocre products repackaged by most game software companies and sold as "educational" software (Ma, 1986). This pertains to the software that uses graphic simulations to concretely present abstract concepts, and other software packages that have the potential for developing thinking skills. Game software has for the most part tended to be more educational than the actual "education" software. Educators need to overcome the label "game" and seek out potential learning application wherever they exist.

Better game software incorporates two features that are necessary in developing critical thinking skills: the knowledge of the various forms of reasoning, and the need for the correct assessment of statements and observations.

An example of the value in game software for educational purposes can be found in the analysis of two games, Pong and Space Wars, reviewed by Carl Sagan (Sagan, 1978). Sagan points out that there is a learning experience involved in Pong which depends essentially on Newton's second law of linear motion. The game, according to Sagan, gives the player an intuitive understanding of Newtonian physics through graphic simulation. The game of Space Wars uses inverse gravitational fields set up by a planet to complicate spacecraft flight. To play the game properly a player needs to develop an understanding of Newtonian gravitation that is not only intuitive but concrete, as presented through the graphic simulations.

The type of graphic simulation software mentioned above is exactly what is needed by educators to teach certain abstract concepts. This opens up many possibilities for certain individuals who have not been able to grasp such concepts in the past. Since the physics concepts or laws used that games generally require an understanding of algebraic and analytical statements, not all students are going to readily grasp formulated problems. A student with strong left-hemisphere capabilities needs only to see Newton's second law presented as $F = ma$ to understand the concept (Sagan, 1978). But now educators have at their disposal for the first time, a method whereby students with less developed left-hemisphere capabilities can understand certain concepts, through the process of computer graphic simulations. This game software allows all students the opportunity of developing better analytical and intuitive capabilities, which serve to strengthen their critical thinking skills.

Problem-Solving Procedures

Microcomputers currently on the market employ two distinct information processing models: algorithms and heuristics. Both models serve functional purposes at present, so one is not necessarily better than the other. Algorithms offer procedures that are guaranteed to obtain unique problem solutions in certain steps are followed. Comparatively, heuristics are procedures which use a non-structured method to achieve a problem solution. But while heuristic procedures may lead to a solution, there is no certainty of this.

Algorithmically structured software is presently being used in the classroom to support traditional teaching methods. Since algorithms are the formal procedures guaranteed to produce correct or optimal solutions, they adapt well to the behavioral engineering concept of conditioned learning, as seen in drill and practice software. Relying on empirical principles of verifiability, algorithmic-based software programs are more adaptable to the traditional classroom method of instruction.

Heuristic approaches to teaching have been around since Socrates, but have invariably lived in the shadow of the more popular didactic or lecture method of instruction. This is essentially due to the skill level required of the teacher using heuristics. The lecture method, unlike heuristics, requires more preparatory time on the part of the teacher. Heuristics requires of the teacher a mastery of his/her subject that allows a class to move in whatever direction questions or statements may dictate. Similar to complex critical thinking, the use of heuristics requires a base of knowledge by teacher and student, and most importantly, demands logical procedures in presenting and answering problems.

Fostering heuristic skills in students is the logical progression for students if they wish to understand expert systems. Heuristics would assist students in understanding

how expert systems work, but, unfortunately, would not help in evaluating the probabilistic and fuzzy outputs of these systems. To evaluate expert systems' outputs, students will need skills which transcend heuristics. These evaluative skills can only be found in developed critical thinkers.

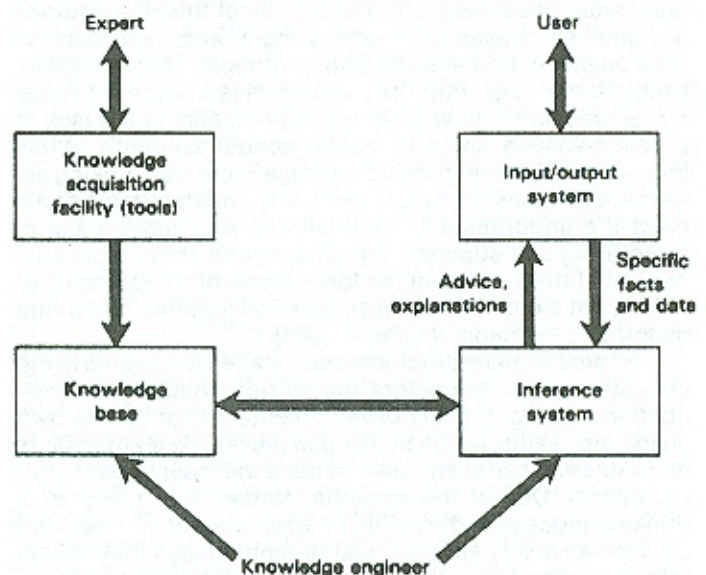
Heuristic methods are currently embodied in software called expert systems. An expert system is the decision-making logic of numerous practitioners encapsulated in a software program. Expert systems form the basis of "artificial intelligence" in computer systems, so called because of the ability to take input data from non-practitioners and return an expert decision, almost as if the machine itself was doing the "thinking."

Artificial Intelligence and Critical Thinking

Artificial intelligence programs operate by erecting data structures to depict certain concepts, and then comparing this with a given example. The variances found specifies the future changes to be made to the data structure. Through this, the program "learns" from "experience" and not by some drawn-out statistical process (as implied by many learning theories).

This type of program, known as expert system, is developed as follows: A knowledge engineer will interrogate numerous experts in a particular field to build a knowledge base and determine the logic involved in making a particular decision (See Figure 1). The knowledge engineer will also work with systems developers who will write the actual computer program to store the logic and knowledge acquired from past experiences and apply the decision logic through the inference system to new applications. The inference system is also programmed to utilize experts' "rules of thumb" to be used when problems do not fit exactly into the existing knowledge base. Note that the inference system and knowledge base are interactive. This is where the "learning" takes place. Also developed is the knowledge acquisition facility, which enables experts to update the system as required. The user can access the system through a highly interactive and use friendly input/output system. The computer will prompt the user for the required data and, using its knowledge information processing system, return to the user the appropriate decision response.

Figure 1. The Expert System (Feigenbaum and McCorduck, 1983)



Conclusion

Teaching critical thinking will become extremely important as computers move toward the use of expert systems software. While expert systems are based on heuristics, this is still, at best, only dealing with probabilities. To maximize the potential of the new expert systems, operators will have to critically evaluate output from these systems. Unlike the output of algorithmic-based computers, an expert system's output is not black and white, but requires critical evaluation.

At the present time, only humans are capable of proposing problems and formulating theories. In this same frame of thought, only humans can decide whether to accept or reject a computer's output. In assessing computer output, the decision process used by the operator must surpass the analysis done by the computer. This implies that human's need to apply a thinking and decision-making process superior to that of the computer's. This process is criti-

cal thinking. Developing applied critical thinking skills in students seems the most effective and efficient use of current and future computer technology. Technology itself is a process, and computers are merely one example of this process that will impact on education. Microcomputers will force education into a process-oriented learning environment, and the development of reason and thinking skills will be the foundation of this process.

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