The Risk of Robotization

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***Abstract*—The advent of digital computers has ushered in a revolution that has begun to transform both our society and human life. Most experts are concerned with a division of the society into two classes — "haves" and "have-nots" — regarding the access to the information technology (so-called "Great Divide"). Yet, as a veteran teacher, I have observed a strange trend: while the new generation of computers has become more human-like, a significant fraction of our students of high marks have become more robot-like. Based on new insights gained into human creativity, harmful impacts of robotization will be analyzed and possible solutions will be suggested in two major areas: education and health care.**

***Index Terms*—evidence-based medicine, computer-based education, creativity, education, health care.**

I. Introduction

PERHAPS the digital computer was one of the greatest, if not the greatest, inventions. The advent of inexpensive and high-powered digital computers, which epitomized the microelectronic revolution, has transformed how humans conduct their daily life. Both the industrial revolution and the microelectronic (computer) revolution have led to an increase of human productivity. By mechanization brought about by the industrial revolution, humans were able to delegate some chores of repetitive activities to machines, thus speeding up manufacturing processes. By robotization brought about by the microelectronic revolution, not only humans were able to let machines manage chores with lightning speeds, and with incredible accuracy and reliability, but also were able to instruct machines to perform intellectual tasks and decision-making. In the past few centuries, humans were largely able to cope with some negative social changes brought about by the industrial revolution; the benefits seemed to have outweighed the shortcomings. Now, the impact of the computer revolution is still evolving. The positive aspects of its impact are well recognized. It has generated a flurry of bandwagon phenomena of computerization in almost every wake of life. However, not all changes are positive. It is time to examine the negative aspects and to plan for necessary remedies so as to cope with these changes. In this article, we shall examine two major areas of human affairs: education and health care. In particular, we shall analyze the problems from the point of view of how the human brain works (cognitive science) and how a computer or robot works (artificial intelligence). In order to set the stage, we shall first briefly discuss how humans perform creative work. Specifically, we shall focus on the chance-configuration theory of creative problem solving, proposed by Simonton [1]. We have recently demonstrated that, by recasting Simonton's theory in terms of pattern recognition in the context of parallel processing and sequential processing, it is possible to explain elusive terms such as insight, intuition and inspiration in concrete terms [2].

By regarding learning as a reverse process of discovery or even re-discovery, human learning shares the same factors governing creative problem solving. Since the appearance, in 1983, of a document entitled "A Nation at Risk," which contained the well-known punch line "a rising tide of mediocrity," the U.S. has undergone repeated educational reforms [3]. In recent years, much effort has been devoted to "computerizing" education, most notably the practice of distance education by means of the Internet technology. Many experts in the educational community have been concerned with an impending division of the society into two classes: the "have" and the "have-not" regarding access to the information technology — the so-called "Great Divide." Yet, as a veteran teacher, I have observed a strange trend: while the new generations of computers have become more human-like, a significant fraction of our students of high marks have become more robot-like. Stranger still, while admissions to medical school have become harder and harder over years, those successfully admitted have become worse and worse in their intellectual performance. Amidst the fanfare of e-education and distance learning, we shall take a sober look at the negative aspects. Here, our purpose is not to prevent or protest the use of computers and Internet facilities for education and health care in a wholesale manner, but rather to identify problems and suggest remedies to alleviate the problems. Whether we like it or not, computer-based education and health care are here to stay, and there seems no turning back.

The term "creativity" conjures up an image of a genius at work. Since geniuses are a minority constituent of the society, one may wonder how the operation of a genius' mind has any relevance to education, which deals mainly with the majority of citizens. In fact, psychologists have been divided in two schools: elitist and non-elitist views of creativity. The elitist school views geniuses' mind as qualitatively different from that of ordinary but bright people. The non-elitist school claims that there is no fundamental difference between the thought process of geniuses and that of ordinary people. Bailin concluded that what geniuses practice is just "excellent thinking" [4]. But what constitutes excellent thinking remain elusive. Our present

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rendition of Simonton's theory is in favor of the non-elitist view: creativity by geniuses is not fundamentally different from everyday ingenuity. Essentially, geniuses reply on the same thought processes to solve problems but geniuses simply push the process to its extreme.

Thus, it is appropriate to consider a gray scale of creativity. Even in creative scientific work of great importance, science historian Kuhn considered two types of creative work: that of normal science and that of paradigm shift in nature [5]. Although capability of a genius is not a requirement, the work of physicians and police detectives belongs to the category of creative problem solving mainly because of the high frequency of encountering the element of surprise: not every case fits the textbook description. Both physicians and police detectives value much their intuition and experience in problem solving. The success of artificial intelligence and problem-solving computer software has inspired a group of epidemiologists at McMaster University to propose the practice of evidence-based medicine (EBM) [6]. EBM sought to de-emphasize physicians' intuition and experience. Instead, EBM proposed to capitalize on the thirty-years' worth of clinical research and convert valid conclusions into a database. According to EBM, a new-age physician must master the basic technique of using the computer to access this vast database and to analyze patient data in light of this database. The use of computers to make diagnosis and propose treatments saves time and money. This proposal suited the need of the current health-care industry. For years, the health-care industry has been trying to algorithmize medicine for the purpose of setting a uniform standard for health-care delivery. The combined effort is to enhance the utilization of digital computers in the hope that it will bring out the same advantages that have transpired in commerce and the banking industry. Again, we shall evaluate the approach of EBM from the point of view of creative problem solving.

II. Simonton's Chance-Configuration Theory

Simonton's theory stipulates three stages of problem solving: blind variation, selection and retention [1]. It mimics the evolutionary process of random variation, natural selection, and reproduction. Creative problem solving starts with searching for candidate solutions (blind variation). It is then followed by the recognition of one or several likely solutions (selection) and subsequent verification (retention). Simian was among the first to point out that creative problem solving involves recognition [7]. If we regard a given problem as a pattern and regard all available or conceivable candidate solutions as templates, then the creative process is tantamount to pattern recognition. The first and second stages of Simonton's model can be treated, respectively, as the processes of searching for and matching candidate templates to a given pattern. Usually, more than one candidate solution can be found but only a few or none are actually valid. The verification phase subjects all candidate solutions to rigorous logical scrutiny. In problem solving, the "space" that contains all theoretically possible solutions is commonly known as the *search space*. Usually, the search space is too vast to be searched systematically or exhaustively in real time. Often, the search space is infinite or poorly defined for a novel problem. The approach of searching the most promising portion of the search space is known as heuristic searching in operations research [7]–[8].

Basically, there are two modes of thinking: visual thinking and verbal thinking [9]–[12]. Visual thinking has long been recognized to be a highly valuable process in creative problem solving. Accomplished physicists, such as Albert Einstein and Richard Feynman, have testified that visual thinking was their predominant mode of thinking [13]. Francis Bacon pointed out that words wonderfully obstruct understanding [14]. Visual thinking offers significant advantages during both the search and match phases because the recognition is not limited or restricted by words; it makes possible random access to plausible solutions. But the recognition tends to be highly subjective. In contrast, verbal thinking offers speed and objectivity as the main advantages.

The mode of visual thinking is not limited to the use of visual sense. It can be generalized to include other somatic senses. Mozart claimed that he was able to hold a piece of music in its entirety in his brain [15]. What he did was tonal thinking. Thus, visual thinking can be generalized to pattern-based reasoning (or, simply, picture-based reasoning since most scientific thinking involves visual imagery) whereas verbal thinking is characterized by rule-based reasoning. Based on the split-brain research pioneered by Roger Sperry [16], [17], it has long been known that the two cerebral hemispheres are specialized in different functions. The dominant hemisphere (left hemisphere for most right-handed individuals) specializes in analytic cognition: its function is therefore algorithmic and sequential in nature [18]–[21]. In contrast, the non-dominant hemisphere specializes in the perception of holistic and synthetic relations. In other words, the left hemisphere specializes in sequential processing, whereas the right hemisphere specializes in parallel processing [22]. It is apparent that pattern-based reasoning is a parallel process: the "goodness" of a match between a template and the visual pattern must be judged as a whole. On the other hand, rule-based reasoning is a sequential process because enunciation of a rule must be made in terms of a sequential presentation of words or symbols. Logical reasoning is a special case of rule-based reasoning, which invokes only well-established and universally accepted rules. Concepts are rules that encompass a variety of different phenomena that share the fundamental patterns of reasoning.

In searching and matching candidate solutions to a given problem pattern, it is possible to use either rule-based or pattern-based reasoning. By invoking rule-based reasoning, the problem solver examines every known rule (or theorem, in mathematics) and considers whether any of them match the problem. However, rule-based reasoning is not suitable for finding novel rules or rules that cannot be constructed by means of a recombination of existing rules. Thus, rule-based reasoning may often be too restrictive to allow for subtle but potentially useful solutions to be recognized. In the verification phase, only rule-based reasoning applies, and the process is strictly objective unless a mistake is made. By direct inference, practitioners of exclusively rule-based reasoning are expected to excel in logical reasoning. That may be the case for some practitioners but I personally found many of them to be poor logicians. Why? If a topic is learned simply as some collection of meaningless rules, it is likely to misuse an irrelevant rule, or abuse a relevant rule beyond its range of validity, during the verification phase.

In this interpretation, Sigmund Freud's *primary-process thinking* [23] can be identified with the parallel process (picture-based reasoning) during the search and match phases. On the other hand, Freud's secondary-process thinking can be identified with sequential process (rule-based reasoning) during the verification phase. The unconscious process during the incubation period, as alluded to by mathematician Henri Poincaré [24], can thus be identified as the effect of defocused attention, resulting in an expansion of the search space. For decades, psychologists have been groping for meaning regarding the elusive concepts of intuition and insight. Sternberg and Davidson [25] suggested, "[W]hat we need most in the study of insight are some new insights!" Ironically, psychologists found these terms difficult to define, presumably because intuition as well as insight is predominantly a parallel process; defining these terms requires a serial-to-parallel conversion (verbalization).

III. Rule-Based Learning vs. Picture-Based Learning

Most, if not all, competent teachers know that rote memorization is an inferior mode of learning as compared to genuine understanding. It came first as a surprise to myself in my 25 years of teaching that there is at least two types of understanding: understanding based on picture-based reasoning and understanding based on rule-based reasoning. In the latter mode (to be called rule-based learning), students learn the subject as a "cook-book" recipe. They memorized the rules (major conclusions) and learned how to manipulate the rules to get the right answers. But there is no feeling of certainty regarding the validity of the learned rules. The popularity of rule-based learning has been increasing over years. The trend was so obvious that no statistical analysis was required to validate the observation of an attentive teacher.

The question is: why did the practice of rule-based reasoning increase in recent years? According to students' testimony, rule-based learning is an efficient short cut to study for good grades. For a while I was in search of the clues of its popularity. Without going into detail and without making an attempt to validate my observations, let me just state the clues as my speculation. I believe that the true culprit is standardized testing. Standardized testing was installed more than half a century ago as SAT (scholastic achievement test) in the United States [26], [27]. By expanding the access of colleges to graduates on non-elite high schools, the SAT has been enormously successful. The problem is: it is very difficult to maintain a valid pool of test questions that effectively test for genuine understanding based on picture-based learning. By memorizing a large collection of old test questions, it is possible to answer test questions of a similar nature without genuine understanding. In other words, however innovative a test question may be for testing understanding, it can be learned by means of rule-based reasoning once the test question becomes known, and its novelty becomes tarnished. In fact, even some essay questions, such as "describe the mechanism of nerve excitation," share the same fate, but the flaws in understanding are easier to spot in an essay test by an observant teacher. For example, an inadvertent transposition of two sequential logical statements makes the underlying thought process absurd, thus betraying a misunderstanding. Besides, in vying for a good grade, students often make additional but irrelevant statements, which again betrays their misunderstanding.

In my opinions, standardized testing is a powerful way to enforce exclusively rule-based reasoning [28]. In answering a test question, the students are forced to thinking along the lines suggested by the [usually] five alternative statements, and to judge on their individual validity. It strongly discourages divergent thinking by a penalty of lost time in taking the test. It is like learning to ride a bicycle with the training wheels permanently attached. No wonder students trained under the system can hardly write intelligibly because taking a standardized test is a relatively passive activity, with almost no need of formulating ideas. Without cultivated divergent thinking, the students suffer in the search phase for excessive restriction of the search space. Strict adherence to rules also impairs the match phase because many analogies not linked by words simply elude the practitioners of rule-based learning. For reasons stated earlier, they also suffer in the verification phase because they tend to be poor logicians. In addition, standardized testing also fosters a sloppy attitude: many students did not even bother to read all five statements; they stop and jump to the next question once a correct choice has been found. The practice also tends to cultivate a one-track mind. Students so trained have trouble handing two independent variables let alone multiple factors that interact nonlinearly. Education thus dwindles to a process of reverse enlightenment or, as Americans aptly put it, a process of "dumbing down."

The next question is: why did SAT work before but begin to exhibit its flaws only in recent decades. Again, without making any attempt to validate my opinions, I will simply state it as a speculation and invites future investigators to validate or refute it. I believe that it is the change of the academic learning environment that cripples standardized testing. The main factors of changes are information explosion and fierce competition. Information explosion and the excessive emphasis of domain-specific knowledge have overwhelmed most students and forced many of them to abandon the more time-consuming endeavor of achieving a genuine understanding. Increasing competition in the job market or in the admission to professional schools forces some students to study for good grades and good grades alone. Rule-based learning does not actually save time, because endless variations of the same test question must be memorized separately. Besides, the retention of learned subjects tend to be short. But neither the students nor the school administration really care [29]. It was rather odd to repeatedly observe that B students remember topics learned more than a year before but A students tend to forget as if they have never taken the course before. But short retention is not a problem for students who crave good grades only. In fact, a medical student even confessed to me that she could not care less whether what she had learned are scientific truths or not, "because there is too much to learn."

It appears that the current situation may be alleviated without a major disruption by partially replacing standardized test questions with non-regurgitation types of essay questions. Grade chasers may be forced to abandon the practice of rule-based learning. To reinforcing the effect of this change, there should be a concurrent de-emphasizing of domain specific knowledge. Prior to this technology-generated information explosion, Kelly West [30] warned that most knowledge transferred to medical students in school would either become obsolete or forgotten, by the time they practice medicine. It is even more so today. Few people can remember, for an extended period, factual information acquired by purely rote memorization, if they use it only once at the time of examination. However, experience indicates that clinicians can remember this knowledge, without much effort, if they use it routinely on a daily basis, such as normal blood electrolyte concentrations. Regarding the excessive emphasis on domain-specific knowledge, John West, a well-known physiologist and textbook author, pointed out a chilling prospect: "In fact, in our medical school there is continual pressure from some courses to increase the amount of material and expand their courses because this can bolster their case for more resources" (p. 389 of [31]). Apparently, there is something seriously wrong about the current popular faculty reward system, administered by medical school administrators, that promotes this type of "cancerous" growth.

IV. Critique of Computer-Based Education

Following the glamorous trend of the computer revolution, many teachers are actively engaged in the search for novel teaching methods by means of computer-aided education. Emphasis is often laid on how students can efficiently search and retrieve information, but little attention has been paid to how these methods can help students filter and organize the information before committing it to long-term memory [32]. Without a doubt, information explosion will be further exacerbated by the relative ease of generating and disseminating information, and the resulting overload will further discourage thinking. As compared to conventional textbooks, quality control of the Internet content is even more difficult for obvious reason. Low quality control will be certainly reflected in an exaggerated expansion of knowledge: now fallacies and valid knowledge may enjoy equal time of representation.

The advantages of computer-aided learning are generally recognized: the ease of making multi-media presentations (with animation, in particular), the ease to update the content, and the widespread availability that transcends the limitation of distances, to name a few. However, some other advantages are rather dubious. For example, the widely acclaimed "links" actually present more problems than solutions. First, the links are pre-determined and limited by the imagination of the designers; there is no provision for creating novel links without first becoming a network "hacker." Second, the limit of screen size of a computer monitor often requires segmentation (serialization) of information with a pre-determined sequence of links. Thus, the current technology of computer-aided education lacks the feasibility of *parallel processing* and *random access* made possible by browsing a book. Although these limitations are not impossible to overcome in the future, the present difficulty actually hampers the practice of picture-based reasoning in spite of the plethora of graphic information that floods the computer screen.

By the same token, a computer-aided literature search still cannot completely replace a search by browsing the shelves of a library. A search based on keyword matching alone is bound to miss a significant fraction of the search space made available by a conventional search that combines both *user-selected* words and pictures. Keywords, no matter how comprehensive and elaborate, can never fully capture the essence of an article. For example, a heretofore-unknown application of a new scientific finding will never appear in the keyword list of the article reporting that finding; only a prepared mind can recognize it and come up with the missing keyword as an after-thought. The tendency of going directly to the "targets" of a successful search also inhibits *exploration* of "collateral" information and prevents *accidental finding* of unexpected information, again because of the lack of feasibility of parallel processing and random access. In both cases, the imagination of the designers imposes a "top-down" restriction, thus making the technology a double-edge sword: the links speed up the search but also eliminate the alternatives that the designers neglect or ignore. In brief, the designers threaten to "robotize" the users, and the users unwittingly relinquish their autonomy. A rush to jump on the bandwagon is thus ill advised. At the present stage, it is better to use the technology as a supplement rather than a replacement of the conventional approach.

V. Critique of Algorithmic and Evidence-Based Medicine

While exclusively rule-based reasoning begins to plague professional medical education, Private U.S. health-care insurance companies have been tacitly enforcing rule-based reasoning in the delivery of health care (managed care system) [33]. In their book *Dangerous Diagnostics*, Nelkin and Tancredi [34] revealed the following practices by many health maintenance organizations (HMOs):

> The process of diagnosis, once dependent on insight, observation, and personal judgment, increasingly relies on diagnostic tests that minimize individual decision making. Technology is considered a more efficient way to decipher patient symptoms, and health-care providers are turning to standardized testing sequences that minimize individual discretion. The use of *algorithms* and *decision trees* illustrates the tendency to seek more scientific grounds for

> diagnostic decisions through the systematic use of tests. Algorithms help to *categorize and channel patients* according to statistical probabilities related to their complaints. Those complaining of certain pains, for example, are given predetermined tests in a sequence that is statistically most likely to reveal relevant information. The sequence of tests is based on the information already known about a condition, the importance of its detection, the penalty for delay, and the least time, risk, and inconvenience for the patient.
>
> Clinicians also use decision trees to help them in patient prognosis. Decision trees derive from operations research and game theory. The tree is used to represent the strategies available to the physician and to calculate the likelihood of specific outcomes if a particular strategy is employed. The relative value of each outcome is described numerically, and a statistical conception of normality helps define proper patient care. (Emphasis added)

I do not deny the values of the operational approach as a supplementary and complementary aid to diagnosis and treatments. On the one hand, I applaud the accomplishment of AI professionals in enriching the resources of health care. On the other hand, I deplore the mindless and heartless decision made by HMO executives to exclude a physician's holistic judgment in the diagnosis and treatments of illnesses. Essentially, the decision trees, also known as *Treatment Pathways*, are sequential algorithms constructed by means of primarily rule-based reasoning. The statistical conception of normality mentioned in the above quotation was established by meta-analyses of data published in the clinical literature. Glossing over by means of the statistical treatment conveniently provided the superficial objectivity and uniformity of methodology in patient management, which might help withstand the test in court in case of malpractice lawsuits. However, the subjectivity of lumping together data from diverse sources in the clinical literature was cleverly hidden from the full view of observers who are not familiar with the methodology or are familiar with it but do not exercise picture-based reasoning in formulating judgment (see Lepper and coworkers' reservation about meta-analyses [35]). Human lives are reduced to mere gambling chips in the game of cost containment. The practice is tantamount to replacement of partially subjective semantic processes in decision making with purely objective syntactic rote processes of algorithms (*algorithmic medicine*).

The above discussion leaves an impression that insurance company executives conspired to undermine the traditional medical practice, and physicians and medical educators were merely reluctant accomplices or innocent bystanders. In reality, there was a co-conspirator from within the medical community: a group of clinical epidemiologists at McMaster University who aspired to the practice of *evidence-based medicine* (EBM) [6], [36]. Boasting to have achieved a "paradigm shift," EBM proponents proclaimed:

> A NEW paradigm for medical practice is emerging. Evidence-based medicine de-emphasizes intuition, unsystematic clinical experience, and pathophysiological rationale as sufficient grounds for clinical decision making and stresses the examination of evidence from clinical research. Evidence-based medicine requires new skills of the physician, including efficient literature searching and the application of formal rules of evidence evaluating the clinical literature.

In Sec. II, we have associated intuition with picture-based reasoning, which is characterized by heuristic searching, parallel processing and random access ("unsystematic" retrieval) of information. In contrast, rule-based reasoning is characterized by systematic, sequential searching for information as well as applications of formal rules in reasoning. What EBM attempts to de-emphasize is essentially picture-based reasoning and genuine understanding based on pathophysiology. A physician is now trained as an agent that goes in between the patients (who furnish their complaints, symptoms and signs) and a rich depository of information and formal rules in the computer database. This is exactly the role played by the agents in John Searle's *Chinese Room* argument [37]–[39]: the agents know how to follow a procedure to translate Chinese into English without ever understanding the Chinese language.

However, EBM advocates were quick to issue a disclaimer: they were not opposed to the use of clinical experience and intuition, to understanding of basic investigations and pathophysiology, and to standard aspects of clinical training; they just wanted to add the EBM approach on top. They correctly dismissed the traditional "cookbook" medicine and heavy reliance on the teaching of authority. They even had a sense of gray scale regarding the reliability of clinical studies, and expected physician training to build the ability to question the authority and make critical assessments — critical appraisal — on the validity of clinical studies on their own. At the foundation of EBM is the literature of clinical research based on systematic and rigorous methodology acquired over the past 30 years. The tools to access this literature include meta-analysis and a profusion of articles on how to access, evaluate, and interpret the medical literature.

Regrettably, EBM advocates cannot have it both ways. As explained in previous sections, medical students are already overloaded with domain-specific knowledge. It is extremely unlikely that they will be able to regain their intuition when they are lured with an additional temptation to relinquish their judgment and delegate it to digital computers. The Evidence-Based Medicine Working Group pointed out that physicians often read just the introduction and the discussion sections, while skipping the method section, when they consulted the clinical literature. They thought that the practice deprives physicians of their ability to judge the validity of what they had read in the clinical literature.

As a comparison, let us consider the teaching of physics. Without consulting the original physics literature, motivated students who study physics are usually able to make valid judgment — to a reasonable extent — of the content of a physics textbook. A good textbook reduces the readers' reliance on authority, although it does not completely eliminate the reliance; that goes a long way. What EBM advocates should have done is: write better textbooks to make cryptic clinical methodology intuitively understandable to medical students, as was done in the past by physics textbook authors on behalf of physics students. Instead, EBM advocates came up with a rule-based algorithm to help physicians make judgment, thus evading their responsibility as medical educators.

For reasons already presented in previous sections, the EBM approach is inherently flawed because of its reliance on computer-based literature searching and a set of *formal rules* to make critical appraisals. The EBM approach will not steer physicians away from "cookbook" medicine but instead towards it; the computer database merely replaces their traditional "cookbook." It will not diminish the reliance of practicing physicians on authority but actually subject them to the dictatorship of digital computers and invisible programmers and clinical experts whom they cannot readily question or challenge. The EBM advocates thus fell into the same pitfalls, which they had pledged to avoid.

Eventually, practicing physicians must relinquish their independent judgment, and rely upon the terse summaries or formal rules and simplified criteria provided by the authority. Ultimately, they will have no choice but to stop thinking. Residency training of physicians thus dwindles to the production of a new breed of "robotized" physicians — robodocs — that practice exclusively rule-based reasoning with the help of a digital computer and invisible experts. In other words, the EBM approach provides physicians with a legitimate escape from their responsibility of judgment, and that suits the HMO executives well. EBM advocates probably would not admit it, in view of their disclaimer.

It is well known that handling of digital information that does not make intuitive sense is prone to errors. It is probably the reason why there was an increase of the incidence of "friendly fire" accidents in the battle fields, as a consequence of the advent of high-tech weaponry: it is difficult to recognize that one is actually aiming at friends instead of foes, or even at oneself, by just looking at the numerical coordinate information that controls the launching of a cruise missile. Besides, a cruise missile only takes orders from its controller. It harbors neither affection for friends nor hatred towards foes, and is essentially selfless. It is not clear how EBM advocates manage to minimize errors and make error corrections, especially if physicians staffed at the front line are forced to overwork without adequate rest. The likelihood of blunders committed by an exhausted medical staff is significantly increased by the advent of managed care systems, of which the executives are well known for their so-called bean-counter mentality. I suspect that the incidence of "friendly poisoning or injury," and even "friendly killing" of patients will rise sharply with the advent of EBM.

Our position may seem inconsistent. If we value so much the accomplishment achieved by Simon's problem-solving programs [2], why are we opposed so much to the EBM approach, which merely advocates using problem-solving programs to deliver health care? The main reason is: to err on the safe side. Failure of a problem-solving program in making novel scientific discoveries is no big deal, whereas failure of a problem-solving program in delivering health care means someone may have to die unnecessarily. This is a consideration that health-care professionals must keep in mind.

No faulty strategies can come into being and flourish without having some redeeming values. Without any doubt, EBM is an effective weapon against no-holds-barred claims commonly made by "quackery," such as often associated with alternative medicine. EBM also serves as an effective defense of frivolous litigation in malpractice lawsuits. Since the late 20th century, physicians have been forced to conduct extensive routine laboratory tests in order to fend off potential malpractice suits. This costly and time-consuming practice of systematic searching is now replaced with an almost instantaneous and inexpensive practice of *virtual* systematic searching, e.g., a 30-minute computer search at a cost of \$2.68 (Canadian dollars), according to The Evidence-Based Medicine Working Group. Thus, the pundits claim that EBM is needed to hold down skyrocketing of the health-care cost. EBM prevents fraudulent claims made by some unscrupulous patients and/or ill-motivated physicians but, at the same time, restricts the legitimate freedom of well-meaning physicians in safeguarding individuals' health. The situation is analogous to what has been encountered in environmental and health hazard issues: quantified data and rule-based reasoning are needed to combat Americans' national penchant for litigation, but, at the same time, undermine legitimate precautions against poorly understood environmental hazards. In both cases, the solution seems worse than the problem.

Perhaps it is a timely wake-up call for all Americans. Their relentless and often groundless pursuits of litigation come with a big price-tag: the prevalent practice of exclusively rule-based reasoning may ultimately cost them their collective and individual health. The trend can, in principle, lead to the untimely demise of democracy and Western civilization. People who abuse their privilege (of freedom and good health-care services) simply do not deserve the privilege and may eventually lose it.

I do not object to the use of EBM as a supplementary and complementary approach by physicians who still can call the ultimate shot. However, common sense tells me that the outcome is going to be something similar to a consequence of the prevalent use of hand-held calculators: a high-achiever in our graduate program was unable to calculate, with or without a calculator, the product of 100,000,000,000,000 and 0.00000000000001 simply because the number of digits exceeds the mantissa of her calculator! The irony is: the cognitive profile of an increasing number of medical graduates produced by our failing educational system fits the EBM job description. It looks like that a faulty educational system and a faulty paradigm of medical practice are going to sustain each other by becoming symbiotic. The practice of EBM will breed more incompetent physicians, and the plethora of incompetent physicians will need EBM to cover their collective incompetence. It makes one wonder whether it was the egg first or the chicken first.

There is, however, a possibility that this dire prediction could be wrong: future generations of computers — biocomputers — may be capable of thinking like humans, without the serious handicaps of digital computers. In order for EBM to work satisfactorily, these futuristic computers must also be capable of explaining the rationale behind its decision to the physicians in charge *and* the physicians in charge must be able to understand what the computers attempt to explain. Computers that can only process formal rules *and* medical graduates that can only perform exclusively rule-based reasoning simply will not do. Until then, EBM should be treated as a nascent basic research topic; the technology is not yet ripe for harvest and ready for clinical applications. Presently, neither the most advanced computers nor physicians trained to master exclusively rule-based reasoning qualify for the task.

VI. Summarizing Remarks

Evolution led to cerebral lateralization of higher mammals. Modern interpretation associates the function of the dominant (left) hemisphere with routine tasks that can be cast in terms of algorithms whereas the nondominant hemisphere is involved in elaboration of novel solutions and in holistic judgment. It has long been known that visual thinking offers an advantage in creative problem solving. However, both hemispheres play important roles in the creative process.

In a recent article [2], I evaluated various models of the creative process in terms of cognitive science and artificial intelligence. In particular, Simonton's chance-configuration theory was interpreted in terms of pattern recognition — a given problem as the pattern and all candidate solutions as templates. In the normal mode of thought processes, both visual and verbal thinking — i.e. picture-based and rule-based reasoning — can be used in the search for plausible candidate solutions, but verbal thinking must be used to implement the logical verification of a selected solution. It can be shown that visual thinking is superior in terms of the search space and the ability to match templates to a pattern but verbal thinking offers speed and objectivity. Ideally, the brain is flexible enough to switch between the two modes of thinking as the appropriate demand arises.

Under the pressure of the information explosion and increasingly fierce competition, the routine use of standardized testing in biomedical education have led to a new trend of exclusively using rule-based reasoning for learning and problem solving. This is in part because picture-based reasoning offers little advantage in taking standardized tests. The information explosion also prevents some students from devoting time to thinking. The outcome has been devastating: students are incapable of solving novel problems although they can solve problem by invoking a "cook-book" recipe without fundamental understanding. In addition, the retention of acquired knowledge appears to be rather short-lived because of superficial understanding or a total lack of it. Students make good grades primarily through a dedicated effort of memorizing old test questions. The need to combat this trend forces the teachers to write trivial-pursuit types of questions, which further demands memorization of detailed information. In the extreme cases, students learn keywords and match them in multiple-choice tests accordingly. It is tantamount to an arms race that escalates with time until one side can no longer afford to continue. Presently, the grades assigned in accordance with the performance on standardized tests are no longer correlated with problem solving abilities and/or the retention of knowledge. The examinations thus exert a regressive selection pressure and threaten to undo what had been accomplished through evolution — cerebral lateralization. There is of course no immediate danger in the change of gene pool but the social impact is far more imminent. At the social level, the principle of survival of the fittest tends to eliminate students who are inclined to think and to preserve students who are good at memorizing meaningless information albeit only for a short time. The outcome is much worse than frequently criticized grade inflation: it is *grade inversion*.

According to my personal observation, prolonged exposures to standardized tests affects all three phases of creative problem solving in students. In the first phase, students tend to restrict their search space to what is prescribed by the test questions; divergent thinking is suppressed. In the second phase, students can match potential solutions to a problem only if explicit keywords appear in the statement; students often do not recognize an old problem if a different set of keywords is used. In the third phase, students tend to misuse irrelevant rules or abuse relevant rules beyond the range of validity for lack of understanding of the rules. According to a Japanese colleague, the acquired habit of answering the easiest question first is often transported to the work place: whenever a selection is allowed an employee tends to pick the least challenging project (G. Matsumoto, personal communication).

The trend appears in spite of another trend: it is getting harder and harder to be accepted and admitted to a medical school. The combined trend casts a doubt on the cherished capitalist tenet: competition breeds excellence. In a book entitled "Intrinsic Motivation and Self-determination in Human Behavior," sociologists Edward Deci and Richard Ryan [40] demonstrated that external rewards ultimately undermine intrinsic motivation, in spite of some claims to the contrary. A renewed controversy actually flared up in 1999 [41], [42]. Interested readers are referred to a series of articles in Psychological Bulletin, Volume 125, No. 6, 1999. Actually, these sociological studies echoed what has been commonly known in psychology: Yerkes-Dodson law [43]. Essentially, the law stipulates that cognitive performance improves with increasing arousal to a certain point, beyond which the performance declines. The motivation of some students to get good grades is so intense that they become emotionally crippled and literally frozen — i.e., stop explorations — upon encounter of an unfamiliar problem (personal observation). Valuable lessons can be learned from these studies at a time when another controversy has just begun: University of California (Berkeley) president Richard Atkinson's decision to scrap the verbal and aptitude part of SAT (scholastic aptitude test) for admission requirements. The discussions may also be relevant to the issue of health-care delivery. In this regard, it is curious to note that private U.S. health-care insurance companies have been tacitly enforcing rule-based reasoning in the delivery of health care. The routing of incoming patients and the guidelines of "legitimate" treatment procedures and duration are strictly based on rule-based reasoning. In particular, meta-analyses of the medical literature were used to establish health-care guidelines. A group of epidemiologists, blinded by the enormous success of artificial intelligence, suggested that modern medical practice should be based on a uniform criteria built on the foundation of 30 years' worth of clinical investigations: evidence-based medicine. Rumor had it that *New York Times Magazine* hailed EBM as one of the most influential ideas of the year 2001. EBM advocates believed that physicians have the moral imperative to practice EBM, and began to act with a religious fervor and forcibly demand a conversion. Based on our understanding of biocomputing principles, EBM advocates threatened to undo what humans have gained in cerebral lateralization through evolution. If EBM ever makes its way into the mainstream medical practice, it will probably earn the reputation of the most devastating calamity that befalls human health in the 21st century.

Sadly, as a consequence of such attempts to "algorithmize" education and health care, the meaning and purpose of education and medical training gradually become marginalized and forgotten. Human costs are no longer part of the deliberation; only financial costs and profits matter. The strategy of algorithmization may be acceptable for technological applications and for the purpose of calculating life insurance premiums. However, this strategy is totally unacceptable when it is used in nurturing human minds and in deciding the matter of life and death of *other* human beings.

In spite of my misgivings presented in this article, I am neither an anti-AI fanatic nor an AI detractor, in view of my own track record of promoting molecular electronics and biocomputing research. I merely wish to point out the shortcomings of the current state-of-the-art AI programs for education and health-care delivery. Instead of abandoning the AI approach to education and health care, I would suggest a limited use of these technologies as supplementary and complementary aids to the old-fashioned education and medical practice. In the meantime, using the current state-of-the art computer and Internet technology to reduce the burden of having to memorize a vast amount of domain-specific knowledge, since its access is only a fingertip away. Students as well as health professionals seeking continuing education can use the saved time to enhance their knowledge-manipulation skill in a more fundamental way: recombining both old and new knowledge to generate novel ideas.

Whether the same shortcomings, mentioned in this article, will persist in future generations of computer programs, I know not. There is no reason to assume that existing AI programs have exhausted all tactics of creative problem solving that can possibly be implemented in a digital computer. There is also no good reason to claim that those fatal flaws inherent in sequential processing cannot be circumvented in the future. Strong AI detractors' objections were similar to what transpired in the controversy of primate language capability: the arguments were often based on "what the apes [or computers] had not yet done" [44]. A skillful programmer can simply take hints from strong AI detractors' objections, and then devises clever algorithms to implement what the computers have not yet done. One should not overlook the precedents that gains made in computers' processor speed and memory capacity often made it possible to absorb the large software overhead needed for performing lengthy, sophisticated sequential processing that mimics parallel processing (what I referred to as pseudo-parallel processing [2]), thus making previously impossible task feasible. If science and technology history ever teaches us anything, it is the advice "never say never" — except perhaps just this once now and never again [45].

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References

[1] D. K. Simonton, *Scientific Genius: A Psychology of Science*. Cambridge, New York, Port Chester, Melbourne and Sydney: Cambridge University Press, 1988.

[2] F. T. Hong, "The enigma of creative problem solving: a biocomputing perspective," in *Molecular Electronics: Bio-sensors and Bio-computers*, NATO Science Series II, vol. 96, L. Barsanti, V. Evangelista, P. Gualtieri, V. Passarelli, and S. Vestri, Eds. Dordrecht, Boston and London: Kluwer Academic Publishers, 2003, pp. 457-542.

[3] D. P. Gardner (Ed.), *A Nation At Risk: The Imperative for Educational Reform*. Washington, D.C.: U.S. Government Printing Office, 1983.

[4] S. Bailin, *Achieving Extraordinary Ends: An Essay on Creativity*. Dordrecht, Boston and Lancaster: Kluwer Academic Publishers, 1988, pp. 84-85.

[5] T. S. Kuhn, *The Structure of Scientific Revolutions*, enlarged 2nd ed., Chicago: University of Chicago Press, 1970.

[6] Evidence-Based Medicine Working Group, "Evidence-based medicine: A new approach to teaching the practice of medicine," *J. Amer. Med. Assoc. (JAMA)*, vol. 268, pp. 2420-2425, 1992.

[7] H. A. Simon, "Scientific discovery as problem solving," in *Economics, Bounded Rationality and the Cognitive Revolution*, M. Egidi and R. Marris, Eds. Hants, England, and Brookfield, VT: Edward Elgar Publishing, Ltd, 1992, pp. 102-119.

[8] H. A. Simon and A. Newell, "Heuristic problem solving: the next advance in operations research," *Operations Research*, vol. 6, pp. 1-10, 1958. Reprinted in *Models of Bounded Rationality*, Volume 1: Economic Analysis and Public Policy. H. A. Simon, Ed., Cambridge, MA, and London: MIT Press, 1982, pp. 380-389.

[9] A. Koestler, *The Act of Creation*. London: Arkana, Penguin Books, 1989. Originally published by Hutchinson, London, 1964.

[10] R. Arnheim, *Visual Thinking*. Berkeley, Los Angeles and London: University of California Press, 1969.

[11] T. Bastick, *Intuition: How We Think and Act*. Chichester, New York, Brisbane, Toronto and Singapore: John Wiley and Sons, 1982.

[12] T. G. West, *In the Mind's Eye*, updated Ed. New York: Prometheus Books, 1997.

[13] J. Hadamard, *The Mathematician's Mind: The Psychology of Invention in the Mathematical Field*. Princeton, NJ: Princeton University Press, 1996. Originally published as *The Psychology of Invention in the Mathematical Field*. Princeton, NJ: Princeton University Press, 1945.

[14] F. H. Anderson (Ed.), *Francis Bacon: The New Organon and Related Writings*. Upper Saddle River, NJ: Prentice-Hall, 1960.

[15] E. Holmes, *The Life of Mozart: Including His Correspondence*. C. Hogwood, Ed. (with an introduction and additional notes), London: The Folio Society, pp. 266-270, 1991. Originally published by Chapman and Hall, London, 1845.

[16] R. W. Sperry, Lateral specialization in the surgically separated hemispheres, in *The Neurosciences: Third Study Program*, F. O. Schmitt and F. G. Worden, Eds. Cambridge, MA, and London: MIT Press, 1974, pp. 5-19.

[17] R. Sperry, "Some effects of disconnecting the cerebral hemisphere," *Science*, vol. 217, pp. 1223-1226, 1982.

[18] E. Goldberg, H. G. Vaugham, and L. J. Gerstman, "Nonverbal descriptive systems and hemispheric asymmetry: shape versus texture discrimination," *Brain and Language*, vol. 5, pp. 249-257, 1978.

[19] E. Goldberg and L. D. Costa, "Hemispheric differences in the acquisition and use of descriptive systems," *Brain and Language*, vol. 14, pp. 144-173, 1981.
[20] E. Goldberg, K. Podell, and M. Lovell, "Lateralization of frontal lobe functions and cognitive novelty," *J. Neuropsychiatr.*, vol. 6, pp. 371-378, 1994.
[21] E. Goldberg and K. Podell, Lateralization in the frontal lobe, in *Epilepsy and the Functional Anatomy of the Frontal Lobe*, H. H. Jasper, S. Riggio, and P. S. Goldman-Rakic, Eds. New York: Raven Press, Ltd, 1995, pp. 85-96.
[22] G. Cohen, "Hemispheric differences in serial versus parallel processing," *J. Exp. Psychol*., vol. 97, pp. 349-356, 1973.
[23] E. Kris, *Psychoanalytic Explorations in Art*, New York: International Universities Press, 1952.
[24] H. Poincaré, *The Foundations of Science: Science and Hypothesis, The Value of Science, Science and Method*, translated by G. B. Halsted), New York and Garrison, NY: Science Press, 1913.
[25] R. J. Sternberg and J. E. Davidson, Insight, in *Encyclopedia of Creativity*, vol. 2, M. A. Runco and S. R. Pritzker, Eds. San Diego, London, Boston, New York, Sydney, Tokyo and Toronto: Academic Press, 1999, pp. 57-69.
[26] S. W. Itzkoff, *The Decline of Intelligence in America: A Strategy for National Renewal*, Westport, CT, and London: Praeger, 1994.
[27] R. Flacks, "Should colleges drop the SAT?: yes, it's a move that will improve college admissions," *AFT On Campus (American Federation of Teachers)*, vol. 20, no. 8, p. 4, 2001.
[28] F. T. Hong, "A survival guide to cope with information explosion in the 21st century: picture-based vs. rule-based learning," *21st Webzine*, vol. 3, no. 4, Speed Section, 1998 [Online]. Available: http://www.vxm.com/FHong.html.
[29] H. Gardner, *The Unschooled Mind: How Children Think and How Schools Should Teach*. New York: Basic Books, pp. 1-15, 1991.
[30] K. M. West, "The case against teaching," *J. Medical Education*, vol. 41, pp. 766-771, 1966.
[31] J. B. West, "Thoughts on teaching physiology to medical students in 2002," *The Physiologist*, vol. 45, pp. 389-393, 2002.
[32] K. Bushweller, "Lessons from the analog world: what tomorrow's classrooms can learn from today," *American Educator (American Federation of Teachers)*, vol. 25, no. 3, pp. 30-33,45, 2001.
[33] R. A. Dudley and H. S. Luft, "Managed care in transition," *N. Eng. J. Med.*, vol. 344, pp. 1087-1092, 2001.
[34] D. Nelkin and L. Tancredi, *Dangerous Diagnostics: The Social Power of Biological Information*. Chicago and London: University of Chicago Press, 1994, pp. 60-61.
[35] M. R. Lepper, J. Henderlong, and I. Gingras, "Understanding the effects of extrinsic rewards on intrinsic motivation — uses and abuses of meta-analysis: comment on Deci, Koestner, and Ryan (1999)," *Psychol. Bull.*, vol. 125, pp. 669-676, 1999.
[36] D. L. Sackett, S. E. Straus, W. S. Richardson, W. Rosenberg, and R. B. Haynes, Evidence-Based Medicine: How to Practice and Teach EBM, 2nd ed., Edinburgh, London, New York, Philadelphia, St. Louis, Sydney and Toronto: Churchill Livingstone, 2000.
[37] J. R. Searle, "Minds, brains, and programs," *Behavioral and Brain Sciences*, vol. 3, pp. 417-457, 1980.
[38] J. R. Searle, "Is the brain's mind a computer program?" Sci. Am., vol. 262, no. 1, pp. 26-31, 1990.
[39] J. R. Searle, Chinese room argument, in *The MIT Encyclopedia of the Cognitive Sciences*, R. A. Wilson and F. C. Keil, Eds. Cambridge, MA, and London: MIT Press, 1999, pp. 115-116.
[40] E. L. Deci and R. M. Ryan, *Intrinsic Motivation and Self-Determination in Human Behavior*. New York and London: Plenum Press, 1985.
[41] E. L. Deci, R. Koestner, and R. M. Ryan, "A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation," *Psychol. Bull*., vol. 125, pp. 627-668, 1999.
[42] R. Eisenberger, W. D. Pierce, and J. Cameron, "Effects of reward on intrinsic motivation — negative, neutral, and positive: comment on Deci, Koestner, and Ryan (1999)," *Psychol. Bull*., vol. 125, pp. 677-691, 1999.
[43] R. M. Yerkes and J. D. Dodson, "The relation of strength of stimulus to rapidity of habit-formation," *J. Comparative Neurology and Psychology*, vol. 18, pp. 459-482, 1908.
[44] F. Patterson and E. Linden, *The Education of Koko*. New York: Holt, Rinehart and Winston. 1981, pp. 193-194.
[45] F. T. Hong, "A multi-disciplinary survey of biocomputing: 2. systems and evolutionary levels, and technological applications," in *Information Processing and Living Systems*, Series on Advances in Bioinformatics and Computational Biology, vol. 2, V. B. Bajic and T. W. Tan, Eds., to be published by Imperial College Press, London.

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