

The Dumbing Down Effect of American Public Education

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Abstract—The year 2008 marked the 25th anniversary of the appearance of an important document, *A Nation At Risk*, which castigated the American public education. All subsequent educational reforms resulted in either modest improvement or further deterioration. This article traces the major reasons of failure to excessive emphasis on domain-specific knowledge and logical reasoning. As a consequence, students were overwhelmed with a huge amount of knowledge to be memorized. Their grade performance was achieved at the expense of critical thinking. An indirect reason was the failure of the mainstream psychologists in elucidating factors, which distinguish creative individuals from their less privileged counterparts. In our quest for demystifying the enigma of human's high creativity, we have identified visual thinking as the major missing link in educational reforms. Visual thinking was also the hidden factor in deciding the success or failure of a number of popular educational approaches, which include small group teaching, cooperative learning and constructivism, and a popular corporate technique called brainstorming. In search of historical evidence, it was found that most of the clues to our present solutions had appeared in the 1908 book of Henri Poincaré and the 1908 discovery of Robert M. Yerkes and John D. Dodson. This article revisited their insights in the light of modern cognitive science and computer science, in lieu of a formal commemoration of the 100th anniversary of their discoveries. In the eve of the 400th anniversary of Galileo's epoch-making discovery of Jupiter's moons, it was found that his 1610 book *Sidereus Nuncius (The Starry Messenger)* provided a convenient platform to debate the merits and the shortcomings of different learning approaches.

Index Terms—Creativity theory, critical thinking, educational reform.

I. INTRODUCTION

ABOUT twenty-five years ago, the [U.S.] National Commission on Excellence in Education published a scathing document, *A Nation at Risk* [1]. In its opening section, the document indicated that the educational foundation was being eroded by “a rising tide of mediocrity.” Subsequent reforms had only dubious effects, at best, and often led to

further deterioration, at worst. Those repeated forms incorporated the then-latest advances in educational psychology. It appeared that some crucial factors might have been omitted. It took a radically different approach to uncover these missing factors but the clues had been available a hundred years ago.

On a parallel and independent path while I investigated biological information processing, I was intrigued by the mystery of human high creativity, as practiced by scientific geniuses. Gradually, I became more and more involved, thus transforming a hobby into an obsession. I drew inspiration from introspections of scientific giants, such as Henri Poincaré [2], Albert Einstein [3], and Nikola Tesla [4]. These introspections revealed that geniuses had a penchant for what I called *picture-based reasoning* [5]. Consultations of the music literature revealed something similar. For example, Mozart used a picture metaphor to describe his composing activities [6]. Of course, the thinking style in music is the tonal equivalent of visual thinking. These introspections seemed to point to a common mental faculty in creativity [7], contrary to the popular view of a multitude of different talents [8]. The common denominator is the exceptional capability of *parallel processing* of information, which reminisces the paradigm once preached by *Gestalt* psychologists. In other words, geniuses all had a multi-track mind. However, a multi-track mind is not the monopoly of geniuses. Many ordinary intelligent folks also have a multi-track mind, with perhaps lesser proficiency.

A turning point was my encounter, in the late 1990s, with a new breed of medical students, whom I referred to as *dumb high-achievers*: students who commanded high grades but exhibited poor problem-solving ability. Their thinking style appeared to be diametrically opposite to that of scientific geniuses. I called it *rule-based reasoning*, because they had a tendency to learn science as a collection of well-established rules, much like cookbook recipes or computer algorithm [5]. In other words, dumb high-achievers think like a conventional digital computer; they have a one-track mind and they processed information *sequentially*. On the other hand, students who were instructed to emulate geniuses' preferred thinking style — picture-based reasoning — often showed surprising improvement. At that point, I started to look into the literature of psychology and cognitive science.

It did not take me long to realize that what I referred to as

Dedicated to Professor Tsu-pei Hung of National Taiwan University, whose reasoning process reminded me of Sherlock Holmes.

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picture-based and rule-based reasoning, respectively, have long been known as visual and verbal thinking, respectively, in the psychology literature [9,10]. These two distinct styles of thinking stemmed from the concept of *cerebral lateralization*. The concept was derived from Roger Sperry's split-brain research [11,12]. In its earlier versions, the concept stipulated that the left cerebral hemisphere specializes in linguistic function and the right hemisphere specializes in visuo-spatial and nonverbal cognition. This concept has undergone significant revisions over the past few decades. Generalizations to include other cognitive functions lead to the following interpretation. The left hemisphere specializes in analytic cognition: its function is therefore algorithmic in nature. In contrast, the right hemisphere specializes in the perception of holistic and synthetic relations: its function stresses Gestalt synthesis and pattern recognition. However, this simple dichotomy was dismissed by subsequent investigations as over-simplified. An improved interpretation of hemispheric specialization advanced by Goldberg and coworkers [13], called the *novelty-routinization theory*, eventually elucidated the puzzle and expelled the doubt. According to this revised interpretation, the right hemisphere is critical for the exploratory processing of novel cognitive situations. The left hemisphere is critical for information processing based on preexisting representations and routinized cognitive strategies. The traditional verbal/nonverbal dichotomy of lateralization thus becomes a special case.

It appeared that the right hemisphere governs the preferred thinking style of geniuses, whereas the left hemisphere governs that of dumb high-achievers. It has long been suspected in the literature that creativity may be associated with the right hemisphere activity. However, the so-called "right brain movement," which advocated strengthening the use of the right hemisphere in education, was eventually discredited by mainstream psychologists. Even Einstein's introspection was openly ridiculed in the psychology literature. Among Einstein's detractors, Harris [14] presented an exceptionally harsh criticism with an objective of silencing the "right-brain" movement.

Confusions regarding the role of hemispheres in creativity could be avoided if one recognizes that a scientific report seldom reproduces how the discovery has been made. About 100 years ago, Poincaré said, "It is by logic that we prove, but by intuition that we discover" (p. 274 of [9], p. 2 of [10]). By identifying intuition and logic with picture-based reasoning and rule-based reasoning, respectively, what Poincaré said is tantamount to: it is by picture-based reasoning that geniuses discover, but by rule-based reasoning geniuses prove. By the same token, dumb high-achievers invoked only logic (rule-based reasoning) in generating and verifying solutions. However, there is nothing wrong about rule-based reasoning, if it is used along with picture-based reasoning alternately, if not simultaneously. In point of fact, geniuses also used it during the solution-verifying phase. However, dumb

high-achievers practiced logical reasoning to the complete exclusion of visual thinking. Thus, dumb high-achievers can be equated to practitioners of *exclusively* rule-based reasoning. It was a horrifying shock to me to find that some experts had actually endorsed and even advocated this deviant thinking style (see below). Detailed evidence in support of my present interpretation of human creativity has been published elsewhere [15–18].

Whereas the terms, verbal thinking and visual thinking, are readily linked to the concept of cerebral lateralization, the synonymous terms, rule-based reasoning and picture-based reasoning, were retained because they serve as convenient reminders of the equivalent concepts of sequential and parallel processing, respectively. Incidentally, Mozart was probably the first to recognize the essence of the difference of these two distinct styles of information processing, in spite of the fact that he was born about two hundred years prior to the advent of computer science and artificial intelligence. In his letter to Baron von P (see p. 268 of [6]), Mozart wrote, "Nor do I hear in my imagination the parts *successively*, but I hear them, as it were, all at once (*gleich alles zusammen*)." The identification of the word "successively" and the phrase "all at once" with sequential processing and parallel processing, respectively, appear to be unambiguous.

The concept of cerebral lateralization helped demystify the enigma of human creativity. However, it also bred major misconceptions. The general public and even some scientists held the view that scientists and engineers are good at left-brain-based thinking whereas artists and experts in social sciences and in humanities are good at right-brain-based thinking (see [19] for a general survey of various views). A similar view attributed rational and logical reasoning to scientists and engineers whereas it attributed sensible thinking to artists and humanities experts (rationality vs. sensibility dichotomy). The dichotomy seems to be perfectly in line with Gardner's theory multiple intelligences. The erroneous views had a far-reaching consequence in shaping science education. In particular, it spawned the popular approach of custom-tailoring instructions to students' diverse learning styles. There was no lack of individuals advocating the use of both cerebral hemispheres. However, their view could only grace the pages of popular press (e.g., [20]).

A rare exception was the first-hand account of the subjective inner feeling about the separate function of the two hemispheres [21]. Jill Taylor, Ph.D., a Harvard-trained brain scientist, had a rare form of stroke, which completely obliterated her left hemisphere function for an extended period, and she then fully recovered to tell the true story. Anyone, who is interested in the topic of cerebral lateralization, should not miss this rare gift to mankind. It is beyond reasonable doubt that the left and the right hemisphere function as a sequential (serial) and a parallel processor, respectively. Taylor's introspection clearly indicated the separation of tasks in temporal and spatial processing in the two respective

hemispheres. However, the identification of recognizable spatial patterns and their meaning requires the left hemisphere's participation in terms of contour delineation; the function of the right hemisphere alone reveals a single spatial image *in continuum* without clearly defined boundaries of its subunits, so-to-speak, and, therefore, without a clear meaning. Taylor's report indeed makes sense in terms of the novelty-routinization theory, mentioned above. Whereas detection of novel spatial images is a task of the right hemisphere, classification of these images into recognizable patterns (possibly with a name tag) is a left-hemisphere task.

Contrary to common belief, cerebral lateralization also exists in lower vertebrates, including fish and birds. MacNeilage, Rogers and Vallortigara, along with their colleagues [22], found that a consistent interpretation could be achieved if they assumed that the right hemisphere evolved to detect changes in the environment (novelty detector), whereas the left hemisphere evolved to increase the dexterity of self-motivated routine motor skills of the right side of body (the beak in birds and the right hand in primates, for example) and the ability to see details with the right eye so as to assist the execution of routine tasks (routine executor). This interpretation is consistent with the novelty-routinization theory. They further presented experimental evidence showing the enhanced efficiency of a lateralized brain as compared to a non-lateralized brain, which must perform both types of mental tasks with a compromised efficiency. Previously, we pointed out that creative problem solving requires a "mood swing" between meticulous rule-based reasoning, on the one hand, and permissive picture-based reasoning, on the other hand (p. 528 of [15]). Again, it is not difficult to understand the advantage of cerebral lateralization in the context of creativity.

A two-month stint in the National Changhua University of Education, located in central Taiwan, afforded me a first-hand opportunity to witness how much inroad educational psychologists had made into shaping the education of future teachers for the public educational system (from kindergarten, through primary school to junior high school in Taiwan, or, kindergarten, first grade through 12th grade in the U.S., i.e., the K-12 system). A treatise with a major following in the educational community was recommended to me: *The Neurological Basis of Learning, Development and Discovery: Implications for Science and Mathematics Instruction*, authored by Anton E. Lawson [23]. Strangely, this book managed to concentrate all misconceptions in a single source. However, Lawson's view was by no means unique. Daniel Willingham, whose "Ask the Cognitive Scientist" column frequently appeared in *American Educator* (an official publication of American Federation of Teachers), essentially held the same view [24]. Lawson's treatise thus represented the prevailing view of the mainstream educational psychology. I therefore could conveniently evaluate Lawson's book in lieu of an actual field survey in the U.S. public school system.

A special feature in Lawson's book was his attempt to

reconstruct Galileo's thought process, which led to the 1610 discovery of Jupiter's four largest moons. He used Galileo's book, *Sidereus Nuncius (The Sidereal Messenger or The Starry Messenger)* [25], as the source material for the reconstruction. Lawson then claimed that the reconstructed thought process of Galileo was exactly as his new theory had predicted. He also cited numerous scientific discoveries in the past as collateral supports. In the present article, we shall attempt an alternative reconstruction by analyzing Galileo's report from the perspective of a practitioner of picture-based reasoning.

The validity of a reconstructed thought process is difficult to authenticate without the benefit of the original discoverer's personal approval. Although direct proof is impossible, a comparison of my reconstruction and that of Lawson may shed some light on Galileo's actual thinking process; the merit of each version can be evaluated on basis of the strength of evidence so uncovered. Furthermore, such attempts of reconstruction could be construed as student reports on assigned reading of Galileo's book. A comparison of the two "student reports" could be used as a basis to evaluate the effectiveness of two different styles of student learning. The comparison may give us relevant insights into why the American educational system continued to deteriorate in the past decades. It turned out that the clues so uncovered could also be found in the 1908 book of Poincaré [2] and in an article of Yerkes and Dodson, published in the same year [26]. It was therefore fitting to commemorate the centennial anniversary of these epoch-making discoveries by revisiting these authors' insights and by pondering what could have been different had their words been heeded. It is also fitting to pay tributes to Galileo's 1610 discovery in the eve of its 400th anniversary.

II. THE LURE OF LOGICAL DEDUCTION

Students who first became a novice in scientific research were often told to begin by formulating a working hypothesis prior to performing an experiment. The student is then expected to make predictions based on the working hypothesis and to design experiments to test the predictions. If subsequent experimental observations agree with the hypothesis, the student can conclude that the hypothesis is a valid one. This doctrine is essentially what Lawson advocated in his book. However, a valid hypothesis implies that the investigator knew the correct answer before any experiment had been done. The hypothesis must be either a) a trivial one, b) a corollary of a powerful theory, or c) a product of an exceptionally superior mind. The third possibility was an unlikely one since most, if not all, highly creative scientists indicated that they had had no idea about the correct answer to begin with, and they, by their own admission, were, therefore, incapable of formulating a viable hypothesis in a single leap.

Lawson claimed that his *hypothetico-predictive theory* provides a cognitive foundation of numerous novel scientific discoveries in the past and of students' learning in science

education. Specifically, he presented numerous examples to demonstrate that reasoning in major scientific discoveries fits the “if ... and ... then ... but ... therefore ...” format; Galileo’s revolutionary discovery of Jupiter’s moons was no exception. Readers readily recognize that this format is one of the most common instructions in a number of high-level computer languages. Furthermore, the construction of this particular type of computer algorithm conforms to the Greek practice of syllogism. Essentially, Lawson claimed that novel scientific discoveries were made by means of logical deductions. Superficially, this claim sounded innocuous. However, Lawson also made a heroic effort to prove that Francis Bacon’s induction method is not qualified to be a valid scientific method. By default, the *hypothetico-predictive method* — that is, deductive reasoning — became the *one and only one* scientific method of investigations. Since every educated individual is expected to learn deductive reasoning in school and every competent investigator is expected to have a good command of the skill, what can possibly make a difference in problem-solving ability is the amount of acquired knowledge. This reasoning allowed Lawson to further conclude that the only source of creativity is a broad and deep knowledge base. Previously, Hayes and Weisberg also made essentially the same claim (A detailed critique of Hayes’ and Weisberg’s work can be found in Sec. 4.21 and Sec. 4.22 of [16]). A direct consequence of such a view was: students should be loaded with a vast amount of relevant knowledge. In the age of ever-accelerating information explosion, this educational view became a nightmare of modern students.

Logic is such a seductive word and, at the same time, such an oppressive word that few educated people would dare to oppose Lawson’s claim. Why did Poincaré then claim that discoveries must be made by means of intuition? To understand the latter point, we must go back to a number of creativity models formulated in the previous century. Most of these creativity theories or models separated the creative process into two phases: the solution-generating phase and the solution-verifying phase [27]. Thus, Poincaré’s remark implies that intuitive reasoning predominates in the solution-generating phase, whereas, according to Lawson, the generation of a solution to a novel problem is attributed to deductive reasoning alone. Poincaré did point out the crucial role of logical reasoning in the solution-verification phase. Few people would dispute the importance of logical reasoning in the solution-verifying phase. However, it takes more than just logic to make a novel discovery. Two questions arise. Why did so many scientists mention logical reasoning instead of intuition in their quest for the unknowns? But then what is intuition?

Intuition is a strange concept. Almost everyone knows how to use the term “intuition” and a related term “insight,” but experts found it difficult to define these terms explicitly [28]. In addition, highly creative individuals often had no clues about their source of inspiration even after the fact, as if it were “out of nothing.” In referring to a long-standing problem that he had

just solved, German mathematician Carl Friedrich Gauss said, “The riddle solved itself as lightning strikes, and I myself could not tell or show the connection between what I knew before, what I last used to experiment with, and what produced the final success” (pp. 308-309 of [29]). Incidentally, Tesla also used the lightning metaphor to describe the suddenness of a novel discovery, whereas Archimedes had no time to put on his clothes when he suddenly exclaimed “*Eureka!*” Suddenness is a common feature of many major scientific discoveries but it is seldom, if any, a feature of pure deductive reasoning. This is just another puzzle that befuddled psychologists of the past century.

To make a long story short, we have identified intuition with picture-based reasoning [15,16]. In practicing picture-based reasoning, inspiration arises from a picture or part of a picture rather than from words or equations. Since the hint from a picture or part of a picture is non-verbal in nature, it is difficult to recall in words afterwards. Picture-based reasoning explains why creators, such as Gauss, had no recollection of how he had made the discovery. The interpretation also makes it easy to understand why major discoveries often appeared without prior warning. Performing picture-based reasoning is like piecing together many elementary pieces in a jigsaw puzzle. It is less likely to build up anticipation because the search process for plausible answers tends to be non-sequential or non-systematic in nature. In other words, “random access” to plausible solutions is an inherent feature of parallel processing. An element of surprise is built into the process because of the inability to anticipate what comes next. The puzzle is solved when a crucial piece suddenly snaps into a strategic location, just like a lightning strike or an avalanche. Last but not least, it is also easy to understand why intuition is so difficult to articulate and to define explicitly in words, because a picture generates an overall, vague feeling. No words can define a picture completely. In addition, a difficult and elusive concept, known as serendipity, becomes easy to understand (see Sec. 4.9 of [16] or [17,18]). We shall see what Galileo had revealed explicitly in *Sidereus Nuncius* was only part of his discovery process.

III. GALILEO’S REPORT OF HIS DISCOVERY OF JUPITER’S MOONS

A. Lawson’s reconstruction of Galileo’s thought process

The first question that I am obliged to answer is: If Lawson’s theory is wrong, why was he so successful, at least superficially, in fitting Galileo’s reasoning to the “if ... and ... then ... but ... therefore ...” format? Perhaps the most eloquent answer came from Poincaré (p. 214 of [2]): “Pure logic could never lead us to anything but tautologies; it could create nothing new; not from it alone can any science issue.” Had Lawson dug a little deeper into Galileo’s publications, he would have found that Galileo was not on his side. In his *Dialogue Concerning Two New*

Sciences (p. 105 of [30]), Galileo stated through the word of his surrogate, the fictitious interlocutor Sagredo, “Logic, it appears to me, teaches us how to test the conclusiveness of any argument or demonstration already discovered and completed; but I do not believe that it teaches us to discover correct arguments and demonstrations.”

It is important to realize that the expected format of scientific reports does not demand inclusion of the tortuous process of finding the desired solution. Most readers just wanted to know what had been found to be true. Any author who included the solution-generating phase in a report might cause unnecessary and unwanted confusion of the readers, thus undermining the acceptance of the author’s main messages. Galileo seemed to have attempted to break away from this accepted format; his *Sidereus Nuncius* was written in a journal format of day-to-day observations, which most other investigators would lock up in their file cabinets. Galileo did include some false starts and detours of his reasoning. Still, he probably had more in mind to convince his contemporaries than to satisfy future science historians. No wonder Galileo invoked mostly deductive reasoning to describe his new discovery, and presented his arguments in accordance with the requirement of syllogisms. Lawson merely regurgitated what Galileo had written but translated them into a fancy computer-like language. It is tautologies!

Let us take a closer look at how Lawson had succeeded. On January 8th, Galileo’s journal stated, “All three little stars [which subsequently turned out to be Jupiter’s satellites] were to the west of Jupiter and closer to each other than the previous night.” Thus, Lawson surmised correctly: [if they were fixed stars,] “their positions relative to each other should be the same.” But the observation showed that “the stars are closer together than on the previous night,” [therefore the observation contradicts the prediction of the fixed-star hypothesis]. Note that this reasoning involved only a single-step of logical deduction. What about multi-step logical deductions?

It turned out that the above-mentioned single-step deduction was Lawson’s only success. But it was hardly convincing evidence to support the satellite hypothesis. Those little stars could be new planets, although it might appear quite unlikely to discover a cluster of new planets within a couple of nights. The rest of Lawson’s reconstructions were either irrelevant or downright erroneous. Furthermore, he missed several important messages hidden in Galileo’s narratives. We shall mention a few here.

In his two-month period of observations, Galileo made a casual remark some 14 times: the three little stars formed a straight line, which he found to be parallel to the ecliptic or, equivalently, the zodiac. Lawson merely interpreted the remark as an indication of a non-random distribution of Jupiter’s three moons. Incidentally, Galileo’s remark was derived by induction after repeated observations. Lawson accepted the remark without even raising some eyebrows. This was symptomatic of rule-based reasoning. Since Galileo did not

explicitly mentioned induction while drawing his conclusion, Lawson simply did not recognize the implication of Galileo’s act and he accepted Galileo’s “illegally” obtained conclusion, without any reservation. People who had some rudimentary knowledge about astronomy would have recognized that this “non-random” distribution is a consequence of viewing the satellite orbits in an “edge-on” direction and a consequence of the satellite orbits being in the same plane as the orbit of the Earth. Of course, one needs to think in pictures in order to appreciate Galileo’s remark.

Lawson also missed the significance of Galileo’s description of non-twinkling of the little stars: This observation implies that the light was not from point sources but rather from tiny disks, thus suggesting the proximity of these little stars to the earth, as opposed fixed stars, which would always appear as point sources under the magnification of Galileo’s telescope. Furthermore, Lawson failed to understand the “looping (or zigzag)” motion of outer planets, thus misinterpreting some of Galileo’s reports. Unlike our own Moon, which moves from west to east relative to fixed stars on the celestial hemisphere, outer planets sometimes move forward from west to east (*direct motion*), sometimes standstill (at *station*), and sometimes move from east to west (*retrograde motion*). Usually, it takes months for an outer planet to complete one round of looping motion, i.e., two consecutive reversals are usually separated by months of time. A quick glimpse into Galileo’s reports revealed that Jupiter had undergone too many reversals of motion during the two-month period, if the three or four little stars were regarded as fixed stars. Lawson missed this important clue entirely.

Thus, Lawson’s reconstruction uncovered extremely weak evidence to support Galileo’s satellite hypothesis. It would be insanely reckless for Galileo to have put his own life in jeopardy with such weak evidence. The fact that Galileo’s discovery was eventually accepted means that his contemporaries seemed to have understood a lot more than Lawson did. Note that Lawson had the advantage of additional knowledge accumulated over the past 400 years, to which Galileo’s contemporaries had no access! The master’s own failure dealt a devastating blow to the credibility of his own theory.

B. Reconstruction via picture-based reasoning

My reconstruction of Galileo’s discovery process turned out to be not as easy as I had anticipated, although I was benefited with hints from Galileo’s reports. If I based my judgment on the interval between two consecutive reversals of Jupiter’s relative motion, the earliest possible day to draw the satellite conclusion was January 12th or January 13th. Yet Galileo immediately abandoned the fixed-star hypothesis on January 10th, and he turned “from doubt to astonishment.” By January 11th, Galileo quickly reached the conclusion that these little stars were Jupiter’s satellites. Galileo’s conclusion preceded mine by a two-day margin. Stillman Drake, one of the foremost Galileo scholars, even presented evidence to show that Galileo could

not have reached the conclusion until January 12th (Note 19 on p. 225 of [31]; p. 150 of [32]; also p. 252 of [33]). However, I was willing to give Galileo the benefit of the doubt, because his astonishment caught my attention. I could not draw a conclusion on January 10th or 11th because I had to await another reversal of Jupiter's relative motion. Apparently, Galileo was able to detect the anomaly after seeing only a *single* reversal from direct to retrograde motion! What was his basis of jumping to conclusions so soon? What did I miss?

In order to find the subtle clue that drove Galileo to his conclusion, I must disown any knowledge, which had not been made available to me and to anyone prior to January 11th, 1610. Therefore, I must temporarily forget Galileo's records from January 12th through March 2nd, 1610. In particular, I had to erase my memory about Jupiter's frequent reversals of motion between January 12th and March 2nd. I was not supposed to invoke modern astronomy knowledge, which was not available to Galileo. Failure to do so could only aggravate my own confusion and deepen the mystery.

I re-enacted Galileo's observations in a strictly day-by-day and frame-by-frame fashion, without peeking ahead of his records in *Sidereus Nuncius*. Suddenly, I sensed *something missing* in the picture. By *deliberately* focusing on the picture part of my thought, I eventually succeeded in articulating the "gut" feeling: If it took months rather than days for Jupiter to switch from direct to retrograde motion, and vice versa, why did Jupiter turn from direct to retrograde motion *without* a temporary standstill relative to fixed stars, for at least a few days, if not for weeks? The absence of Jupiter's station was what had astonished Galileo. Yet he said nothing explicitly. Only his astonishment betrayed his "gut feeling." This subtle point eluded most, if not all, Galileo scholars for the past four hundred years.

Ironically, Galileo's astonishment was my indirect clue, which both Drake and Lawson had missed. Presumably, Galileo sensed the anomaly by detecting *incongruity* of his mental pictures while compared what he had observed with what he had expected. Naturally, it was much more difficult for Galileo to say explicitly what was *unexpectedly absent* than what was *unexpectedly present*. Galileo's picture-based reasoning would explain why he had not said it explicitly, for the same reason that Gauss could not recall the clue of his inspiration. However, once the clue has been pinpointed, it is easy to explain it in conventional syllogisms, as I just did, and it became easy to understand why Galileo could draw the conclusion as early as January 11th, 1610.

Another simple piece of evidence in support of the satellite hypothesis could be made clear by sequentially viewing all the graphic diagrams, which Galileo furnished in *Sidereus Nuncius*. During Galileo's 2-month long observations, the four little stars never drifted away from Jupiter for more than 14 arc minutes. It conjures up a specter of four little stars following Jupiter wherever it went during the 2-month period. In fact, it was easy to visually demonstrate the effect by arranging

Galileo's 65 graphic diagrams in an animation sequence. In the spirit of Occam's razor, the satellite interpretation is the simplest explanation. However, the most direct and perhaps also most quantitative evidence in support of the satellite hypothesis is the trajectories of Jupiter's moons as projected onto the celestial hemisphere. If the satellite hypothesis is correct, all four little stars are expected to undergo a *simple harmonic motion* along a straight line in parallel with the *ecliptic*! In spite of the limited accuracy of Galileo's visual estimates, the plotted graph revealed a sinusoid trajectory of Jupiter's outermost moon, *Callisto*. The measured period was 16 days, which was close to the modern accepted value of 16.7 days. Likewise, though less clear, the trajectory of the second largest moon, *Ganymede*, was also sinusoid, which yielded a measured period of 7 days, as compared to the modern accepted value of 7.15 days.

IV. MULTI-STEP LOGICAL DEDUCTIONS

Lawson's success in a single-step logical deduction cautioned me against premature dismissal of the role of deductive reasoning in making *some*, if not *all*, discoveries. Poincaré's wholesale denial of the role of logic in making discoveries might have occasional exceptions. A discovery made by means of a single step deduction may not be a tautology *unless* someone else has made the *same* discovery *previously*. Sherlock Holmes' frequent allusion of elementary deductive reasoning still rang in my ears. Perhaps I should be more cautious and give Lawson and Sherlock Holmes the benefit of the doubt. Still, I suspect that it is not very likely to make a major discovery, in modern time, by means of one-step deductive reasoning, because others could easily have made the same discovery a long time ago. Of course, deductive reasoning is always useful in solving minor and simple daily problems.

In his fictional adventure, Sherlock Holmes' reasoning often involved multiple steps of logical deductions. I suspected that multi-step deductive reasoning might just be an afterthought of Holmes following his prior picture-based reasoning. However, if multi-step syllogisms could be constructed subsequently later during the solution-verifying phase, they could, *in principle*, be "discovered" during the solution-generating phase. This lingering thought sent me into the path of finding out why multi-step deductive reasoning is so much more difficult than single-step deductive reasoning.

Poincaré explained over 100 years ago, "Evidently because it is guided by the general march of the reasoning. A mathematical demonstration is not a simple juxtaposition of syllogisms, it is syllogisms *placed in a certain order*, and the order in which these elements are placed is much more important than the elements themselves" (p. 385 of [2]). The key issue is proper arrangements of syllogisms: how to find the relevant syllogisms and how to find the proper way of arranging them so as to ensure a smooth logic flow? We shall demonstrate the salient point with first encounter between

Sherlock Holmes and, his sidekick, Johan Watson, M.D.

In Chapter 1 of *A Study in Scarlet* [34], Holmes greeted Watson with a now-famous remark: “You have been in Afghanistan, I perceive.” Watson was astonished, and exclaimed, “How on earth did you know that?” Of course, Holmes was a fictional character, but a fictional description often reflected the author’s real-life experience. In fact, the real-life counterparts of Watson and Holmes were Arthur Conan Doyle himself and Joseph Bell, M.D., of the Royal Infirmary of Edinburgh, respectively [35].

In Chapter 2, with a title of the Science of Deduction, Holmes explained his reasoning with four syllogisms, arranged in an easy-to-understand order. He further explained, “From long habit the train of thoughts ran so swiftly through my mind, that I arrived at the conclusion without being conscious of intermediate steps. There were such steps, however. ... The whole train of thought did not occupy a second.” Holmes’ syllogisms certainly fit the “*if ... and ... then ... but ... therefore ...*” algorithm. Willingham [24] claimed that Holmes’ explanation was “not [based] on incredible intelligence or creativity or wild guessing, but on having relevant knowledge.” But the cited facts were not exotic knowledge. Besides, what Holmes had observed must be more than what he mentioned in his syllogisms. How on earth could he select, within a brief second, relevant knowledge from a plethora of observations, let alone arrange them in the *proper* order? In fact, merely reciting the above syllogisms in *silent speech* would take more than one second. I suspect that Holmes must have fit relevant pieces of knowledge together like a jigsaw puzzle; many irrelevant pieces were rejected without actually trying. However, like Gauss, Arthur Conan Doyle (or his alter ego, Sherlock Holmes) was not fully aware of his thought process, and still referred to his thought process as elementary deductive reasoning.

In discussing the thought process of Gregory House, M.D., a contemporary television character and a Holmes clone, Abrams pointed out that all great fictional detectives mistook their methods as deductive, and most, like Holmes, simply scoffed at guesswork [35]. Abrams thought that their thought process was, instead, *abduction*. Abduction was a term introduced by philosopher Charles Peirce. Essentially, it means reasoning backward, or reverse deduction. Abrams made a good point. However, Abrams also made a new mistake. Abduction is not the answer because it cannot fare any better than deduction (see below).

Lawson’s theory is not the answer, either. Galileo’s cryptic report with embedded multi-step syllogisms completely eluded Lawson’s hypothetico-predictive method. In making a sweeping generalization about tautologies, Poincaré obviously considered *only* multi-step deductive reasoning, as is commonly performed in mathematical reasoning with numerous equations. More than once, he mentioned the peril and futility of blind searches for solutions. Poincaré pointed out that most permutations and combinations of syllogisms (or equations) were meaningless, whereas the possibilities of such

operations were virtually infinite so that even a lifetime would not be sufficient to complete the blind searches. Here, Poincaré touched upon an important issue, which, in computer science jargon, is called *combinatorial explosion*: the number of permutations and combinations of reasoning steps grows exponentially with increasing complexity of the problem.

He mentioned an incident occurring an evening when he drank black coffee and could not sleep (p. 387 of [2]). He decided to abandon his persistent efforts, which lasted 15 days, of trying a great number of combinations [of equations] and reaching no results. He wrote about his alternative approach, “Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making stable combination.” His description in terms of the words “collide” and “interlocked” as well as the phrase “stable combination” betrayed his thought as a game of piecing together a jigsaw puzzle. That is, he performed picture-based reasoning. He thus cleverly evaded the wrath of combinatorial explosion, since he did not have to waste his time trying those combinations that had not interlocked into a stable configuration. This was indeed the case in view of what he wrote about what he had done in the following morning: it took him just a few hours to write out the results. This episode reminded me of what Mozart had done on a routine basis. Mozart often completed the entire piece of music in his head, and the subsequent commitment to paper was somewhat automatic, during which Mozart often engaged in other activities concurrently (see p. 238 of [36]). There is little doubt that Poincaré practiced picture-based reasoning, as we can further infer from the following remarks (p. 385 of [2]).

Poincaré wrote, “If I have the feeling, the intuition, so to speak, of this order, so as to perceive *at a glance* the reasoning *as a whole*, I need no longer fear lest I forget one of the elements, for each of them will take its allotted place in the array, and that without any effort of memory on my part.” Interestingly, Poincaré linked intuition and parallel processing together — perceiving *at a glance* the reasoning *as a whole* — with regard to his “general march of the reasoning,” which we now call visual thinking. Unfortunately, Poincaré’s plain French failed to impress the experts; only the proper jargon could have done the trick. Explicitly, Poincaré pointed out that he did not rely on broad and deep knowledge of mathematics or his good memory to solve difficult problems. He said, his memory was not bad, but it would be insufficient to make him a good chess-player. Even Sherlock Holmes warned against indiscriminate acquisition of vast knowledge (Chapter 2 of *A Study in Scarlet*). Under Doyle’s pen, Holmes was portrayed as a person with deficiencies in a number of major areas of science and humanities. Somehow, Holmes seemed to be able to manage to get sufficient in-depth knowledge to solve his cases. I suspected that he had acquired it “just in time”!

Now, let us turn our attention to the concept of abduction, or reverse deduction. Just like (forward) deductive reasoning, abductive reasoning is feasible only if it consists of a single step. Worse yet, for complex matters, there seldom exists a single

cause. In other words, the causes and effects are not a one-to-one correspondence, and reasoning backwards does not always lead to the main cause, even if the main cause is within reach. Note that the wrath of combinatorial explosion put up roadblocks several times. First, one must make multiple attempts of single-step abductive reasoning, for reason just mentioned. That is, abductive reasoning must branch out backward. Second, multi-step abductive reasoning must be summoned, if one succeeded in exhausting all single-step abductions to no avail. Third, *multiple* attempts of *multi*-step abductions must be sought after if one intends to uncover or discover *all* relevant factors. Unless one attempts to *branch out backward several layers deep*, one runs the risk of locking onto the first success, thus becoming a victim of the so-called *confirmation bias*: the tendency to explain away in terms of the *first* available plausible cause, thus missing other more pertinent causes. All these formidable ramifications render the task of abductions no easier than finding a needle in a haystack. Therefore, abduction, in spite of its proponent's fame, is virtually useless for solving complex problems. Abduction or deduction, it was merely an illusion for the same reason that caused Gauss to forget his inspiration. My neurology professor and my mentor at medical school, Tsu-pei Hung, M.D., excelled at presenting lengthy syllogisms during clinico-pathological conferences. He confirmed that he had derived his multi-step syllogisms by reading off a preformed mental map (personal communication, 2007).

Regarding Abrams' allusion of guesswork, picture-based reasoning is indeed guesswork, since the validity of the conjecture is still subject to rigorous verification by means of deductive reasoning. However, it is not sheer guesswork but rather some kind of educated guesswork, which is known as heuristic search in computer science or operations research. Thus, both Poincaré and Holmes knew how to conduct heuristic searches by performing picture-based reasoning, so as to combat combinatorial explosion. It was amazing to witness how much computer science and artificial intelligence that Mozart and Poincaré had understood, in spite of the fact that they never had the benefit of taking a course of computer science or operations research. Intriguingly, a natural ability to conduct heuristic searches often disguises itself as luck. When Poincaré decided not to waste time on trying each and every possibility he could have thought of, he vastly increased his odds of hitting the correct solutions. Likewise, a card counter is usually not welcome in casinos, not because of his or her inexplicable propensity of luck but because of his or her ability to willfully increase the odds of winning a blackjack game. Without a doubt, card counting is a way of conducting heuristic searches in a casino setting. Sadly, Lawson's book did not even include a casual mention of the concept of heuristic search.

Finally, I must answer a question, which has not been raised by any debating parties but which may surface in the mind of readers. Elsewhere I have analyzed rule-based and picture-based reasoning in terms of digital pattern recognition

and analog pattern recognition, respectively (see Sec. 4.6 of [16]). Picture-based reasoning thus demands matching of an observed pattern to pre-conceived templates, of which the distribution is *continuous* and which are, in principle, infinite in numbers. In contrast, templates used for digital pattern recognition are *discrete* in their distribution and tend to be finite in numbers. From this point of view, picture-based reasoning is expected to suffer more severely from combinatorial explosion than rule-based reasoning. Fortunately or unfortunately, *not all* possible templates can be pre-conceived; only *recognizable* templates can be pre-conceived. The number of recognizable templates is relatively miniscule but it can grow with *experience*. This interpretation is in agreement with the observation that intuition is experience-dependent but logic is not [10].

V. WHY DID EXCLUSIVELY RULE-BASED REASONING BECOME MORE PREVALENT?

Although I did not have extensive field data to support my claim, the popularity of exclusively rule-based reasoning became so obvious at the turn of the century that I did not need statistics to ascertain the significance. If so, the question is why? Elsewhere, I have presented a detailed analysis of the sociological factors (Sec. 4.23 of [16]). A brief summary will be given here.

At least, two major factors could be identified: information explosion and fierce competition. Over the past few decades, admissions to medical schools became harder and harder in spite of my observed decline in students' intellectual performance. Not every medical-school teacher would agree to my assessment. Some even claimed that students became smarter and smarter in modern time. The difference was apparently due in part to different methods of evaluation. It is true that students nowadays know much more than their parents' generation did, but they understand considerably less. Standardized testing, commonly used in a large class, is rather insensitive to evaluating students' understanding. Worse yet, standardized testing evaluates primarily understanding at the rule level, whereas only more comprehensive testing such as essay or oral tests can penetrate the camouflage of superficial rule-level understanding. Needless to say, picture-based learning offers no advantages in taking standardized tests. But the effect was not immediately apparent because correct learning approaches also ensure good performance in standardized testing. With the advent of information explosion, some students believed that rule-based learning or sheer rote memorization would offer them a better edge of advantages in attaining high scores. Rule-based learning simply rose to the occasion. Rule-based learning is not exactly learning by rote memorization, because its practitioners know how to manipulate prescribed and pre-learned rules to get the correct answer even when the problem turns out to be not exactly the same as a previously encountered one. Merely recognizing the

type of problems suffices to tip off its practitioners to initiate a previously learned procedure, with or without knowing why. However, its practitioners would encounter a formidable challenge when the problem demands a new recombination of existing rules or demands new rules to be discovered.

The deleterious effect of performance-driven learning seems to be an unexpected consequence of our cherished capitalist tenet: competition breeds excellence. But the side effect has been forecast about a hundred years ago. In 1908, Yerkes and Dodson reported a finding, which is now known as Yerkes-Dodson law [26]. In plain English, the capitalist tenet is true only to a certain extent. Beyond the optimum point, excessive competition leads to a decline of performance. There are profound psychological reasons. However, even at a superficial level, one should expect that excessive competition tends to encourage the performers to take shortcuts. In hindsight, rule-based learning was an ingenious shortcut for students to survive the assault of information explosion, but the shortcut approach happened to undermine students' creativity and to diminish their understanding. Since the inception of the No Child Left Behind Act around the turn of the century, many American K-12 schools began to teach for testing because school funding became tied to student performance. Learning just for testing must be a boring and, at the same time, a stressful experience. No wonder some American K-12 schools had unacceptably high dropout rate. Willingham explained why kids did not like school [37]. He claimed, "Contrary to popular belief, the brain is not designed for thinking. It's designed to save you from having to think." It was a euphemistic way of saying that the brain is designed to regurgitate previously learned solutions of known problems, thus glorifying rule-based learning. In view of the fact that such a fallacy ran unchallenged in the magazine of a teachers' union, it is obvious that the public sentiment gave experts a blanket license to mislead the teachers at large. The teachers' union is simply the wrong target to blame for our collective failure.

Deci and his colleagues explained the peril of grade-driven learning most eloquently [38]: extrinsic rewards undermine intrinsic motivation. It is not difficult to understand why motivation driven by fame, fortune and/or power is not conducive to creativity, since these factors discourage risk taking. Yet creative work often incurs high risks. By the same token, motivation driven by grade performance is not conducive to effective learning. Most educational psychologists did not differentiate between extrinsic and intrinsic motivation. Consequently, student failure was often attributed to lack of motivation. Paradoxically, I have seldom seen students more motivated than our dumb high-achievers. These high-achievers were mainly motivated to attain grade performance but they often could not care less about actual learning or understanding. Likewise, they were not inclined to take risks, which might jeopardize their grades. Consequently, they tended to play it safe. To them, nothing is safer than memorizing standard answers and regurgitating them back to

the teachers. This mindset of modern students was best demonstrated by a recent experience. The test object was the horse puzzle depicted on p. 133 of [17] and on p. 105 of [18]. A student quickly learned how to take advantage of picture-based reasoning to solve the puzzle in less than one minute even though she had had no clue prior to my explanation. The real drama came when she tried to do it the second time and failed. The reason was simple. During first attempt, she relied on her intuition to figure out the strategy on the basis of picture-based reasoning, as she had been suggested to do. For the second attempt, she decided to play it safe and she reverted back to rule-based reasoning, but she could not recall the exact procedure for the same reason that one can hardly describe verbally how to tie a shoelace.

VI. HIDDEN FACTORS UNDERLYING THE SUCCESS OF SMALL GROUP TEACHING AND BRAIN STORMING

Over several decades, small group teaching has been high on the agenda of educational reforms. Consequently, the U.S. government poured a huge amount of money into its implementation. Common sense tells us the advantage of keeping the class size small if not for other reason than adequate individual attention, but the projected effect on learning was dubious. The effectiveness of small group teaching is probably similar to that of brainstorming, widely practiced in the corporate community. These approaches apparently worked well in the hand of experts, but why could not trained teachers bring about the *same* effect? Perhaps the experts knew something else that trained teachers did not know. Or, perhaps the experts did something else unconsciously, which was not included in the training of teachers.

Let us get back to the basic. The advantage of small group teaching was found empirically, i.e., by means of statistical correlation in repeated trials. Group setting was identified as the factor or, at least, the main factor. It is well known that correlation suggests causation but it does not affirm it. It is possible that there is yet another factor that is *loosely* coupled with group setting. That is, there is a hidden factor that hitchhikes with the main superficial factor. When the unidentified factor was present along with the superficial factor, the approach worked, but it did not work when the hidden factor was dissociated from the superficial factor.

My own preliminary observations, based on interactions with students, suggested that the heretofore-unidentified factor might be picture-based reasoning. This factor may be more important that the non-threatening environment provided by the group setting, as suggested by Yerkes-Dodson law. If our interpretation is/were correct, explicitly instructing students to perform picture-based reasoning will/would vastly increase the efficacy of small group teaching, cooperative teaching, and brainstorming. Our preliminary observation seemed to confirm this prediction. Likewise, constructivism tacitly created a

learning environment that is conducive to picture-based reasoning but never identified picture-based reasoning as the essential factor. It is predicted that teaching methods based on constructivism can be enhanced by instruction of picture-based reasoning.

VII. ROLE OF LIBERAL ARTS EDUCATION

Traditionally, liberal arts education was the primary venue for fostering critical thinking, especially for non-science professionals [39]. This practice implied that science education had failed to uphold critical thinking in spite of the common perception that science and critical thinking are inseparable. Although good science demands critical thinking of its original thinkers, it was easy to bypass critical thinking in teaching or learning science because rule-based learning offered a convenient shortcut. However, the shortcut appeared to be less effective in a liberal arts curriculum, in part because of the inherent difficulty of reducing — thus diminishing — knowledge to just formulas or other kinds of recipe-like algorithm. Perhaps this was the reason why liberal arts education was more effective in cultivating critical thinking. The potential effect of science education on critical thinking was further undermined by the prevailing attitude of treating science as nothing more than a depository of canned solutions of technical problems. Therefore, it is possible to build a successful career in science and science-related endeavors by practicing exclusively rule-based reasoning, but it is virtually impossible to do so in most other specialties. (Does anyone wish to hire a defense attorney that could only perform single-step deductions or abductions?) This subtle difference ensured that critical thinking in liberal arts education could still survive the assault brought about by social changes that also brought us dumb high-achievers (in science).

It is obvious that liberal arts education “teaches” critical thinking in an implicit way, which is often described as a process of “osmosis.” Walters thought that emphasis on the skills of critical thinking in a liberal arts curriculum should be supplemented by “training in alternative methodologies that focus on synthetic, dialectic, and creative modes of awareness and expressions” [40]. However, without a valid creativity theory, these proposed methodologies were all just shots in the dark.

Now, picture-based reasoning was found to be the key to critical thinking, explicit and effective methodologies could be designed. Does liberal art education become obsolete? The answer is a resounding no for the following reasons. Creativity and critical thinking cannot be taught out of thin air; a platform is needed to deliver the instructions. As far as non-science students are concerned, the platform remains to be liberal arts. A “logical” inference is: The platform for teaching critical thinking in a science environment is science itself. This logical inference is unfortunately incorrect or, at least, impractical. As explained in previous sections, scientific reports in the

literature seldom contained information regarding how a novel discovery had been made. The alternative is to turn to science history. Regrettably, at the behest of the so-called “translational research” advocated by government funding agencies, science has become increasingly subservient to technology. Naturally, science history commands a low pecking order in government’s funding priority. A vast depository of wisdom remained buried and hidden from plain view. Readily available autobiographies, such as Nikola Tesla’s [4], and introspective reports, such as Poincaré’s book [2], did not receive the attention it deserved. Lawson’s contribution of bringing Galileo’s *Sidereus Nuncius* to educators’ attention was marred by erroneous interpretations. On the other hand, materials suitable for teaching are widely available and accessible in humanities. Authors (writers) and artists were expected to express their imagination without too much inhibition; conformity to logic is not a requirement. So far, I have been able to take advantage of detective stories, such as the Adventures of Sherlock Holmes, and popular television series, such as “Columbo” and “Monk.” Music also provided a rich resource. German composer Richard Wagner often used operas as a vehicle to convey his philosophical ideas, including creativity. *Der Ring des Nibelungen* (in particular, *Siegfried*) showcased the inhibitory effect of fear on creativity whereas *Die Meistersinger von Nürnberg* presented one of the funniest parodies about combinatorial explosion.

Thus, liberal arts education as well as general education, which is a small-scale liberal arts education for science and engineering students, remains the ideal venue to cultivate critical thinking and creativity; almost no additional background in science is required. Now, liberal arts education can be lifted from the “osmosis” level to the explicit level, once we had a better understanding about human creativity and critical thinking. In this regard, some misconception needs to be rectified. Liberal arts appeared to be the proper antidote for the excess of trivial scientific knowledge. In the absence of a deeper understanding as to why liberal arts education works, some misguided educators misconstrued the so-called general education as humanities’ (or social sciences’) turn to force-feed college students with equally trivial knowledge (or just raw information), thus putting the cart in front of the horse. The outcome was dismal, as we could easily expect. Students regarded courses offered in general education as an easy way to get “soft” course credits and also as a “mental vacation” away from the suffocating load of “hard” science courses. Few students took general education seriously. With our newly acquired understanding, emphasis can now be shifted from knowledge to insights, from information to cognitive skills, and from memorization to understanding. Liberal arts education as well as general education could become more attractive to students.

Among liberal arts subjects, music and (graphic) art education deserves a special comment. Music and art education has seldom been regarded as essential or vital. Music and art

activities often served the purpose of beefing up the resume of a college or professional school aspirant for the sole purpose of impressing admissions officers. The role of music and art education in children's cognitive development remains to be explored. Rauscher and co-workers [41] reported what is now known as the Mozart Effect: By exposing 36 college students to 10 minutes of listening to Mozart's Sonata for Two Pianos in D Major, their performance on IQ tests for spatial-temporal tasks was enhanced. Levitin [42] dismissed the validity of the Mozart effect because no plausible mechanism had been proposed to link music listening with performance on spatial-reasoning tasks. However, the dismissal was premature. It is true that a single-step logical deduction easily links music listening to temporal-reasoning tasks but not to spatial-reasoning tasks. Such a mechanism is, however, not inconceivable if we are willing to invoke multi-step logical deductions. Western classical music is synonymous with polyphonic music and/or monophonic music with polyphonic accompaniments (harmony and counterpoint). Obviously, simultaneously hearing different voices in a chorus demands a proficiency in *parallel processing*. So does a spatial-reasoning task. In my personal opinion, Western classical music offers one of the best training grounds for a multi-track mind, whereas science education, as being implemented presently, became one of the most potent training regimes to enforce a one-track mind. There is little doubt that music and art education is important in shaping cognitive skills (see discussion in Sec. 4.8 of [16]). The question is: To what extent? How to make it work better? The Mozart effect is therefore a respectable topic, which deserves further investigations. The next time a budget cut for music and art education is being contemplated, short-sighted politicians ought to have a second thought: Is it cheaper to fund music and art education or to fund drug rehabilitation programs and to build additional prison facilities? What if music and art education can decrease the dropout rate in high schools? These are not idle questions. The implication of music and art education is more than meet the eyes.

VIII. GENERAL DISCUSSIONS AND CONCLUSIONS

One of the original intents of public education was to enlighten the citizenry. The prosperity and affluence in developed countries were the fruit of public education. In the past, the dumbing down effect of public education was mentioned only in anecdotes. We could afford to ignore it because it was not generally true. Even when it happened it could be easily explained away, but it did not really go away. Eventually, it reached an alarming level, and it ushered in the appearance of the document, *A Nation At Risk*, about a quarter century ago.

Initially, the problem seemed to be limited to the so-called K-12 (kindergarten to 12th grade) education, thus leaving higher education intact. This observation offered a convenient correlation. Since unionism was primarily active at the K-12

level rather than at the college and university level, it was easy to blame teachers' unions for sustaining and perpetuating mediocrity of teachers' quality. Once this perception was ingrained and firmly lodged in the public consciousness, the stigma of unionism persisted. Besides, the rise of the right-wing politics in the late 20th century also made it politically correct to disapprove unionism. The experts were thus relieved of their obligation of searching for deeper reasons and more effective cures. When higher education began to deteriorate, we could continue to blame the unions for feeding college and universities with inferior products of high school education, since college and universities are on the receiving end. We thus missed the opportunity to explore and discover other hidden but perhaps more serious causes. Excessive emphasis on research at the expense of teaching at the college and university level also helped to sustain the status quo [43].

However, teachers' unions did respond positively to the warning of *A Nation at Risk*, by requesting a partnership of colleges and universities in a joint effort to upgrade the standard of teachers' education, thus resulting in significant improvement of teachers' training and induction, according to an article in *AFT [American Federation of Teachers] On Campus* [44], which appeared at the 20th anniversary of the publication of *A Nation at Risk*. Two seemingly unrelated articles, which also appeared in the same issue, painted a completely different picture, thus casting doubt on the alleged improvement. One of them reported an increasing incidence of psychological problems of incoming college freshmen, of which stress/anxiety problems topped the list since 1994 [45]. The other singled out "grade inflation" as an explanation of the superficial improvement [46].

The three articles cited above might not be totally unrelated; they might report three interlocking pieces from the same jigsaw puzzle. Merely raising the standard of test scores of either teachers in training or students in school would not alleviate the situation. The problem was, grades did not always reflect learning if rule-based learning had already made a significant inroad into the educational system. The boredom and burden of learning would drive up the incidence of students' psychological problems. An article in the same magazine two years later reported further deterioration of the situation [47]. For example, over a mere decade, the number of students with depression had doubled, the number of suicidal students had tripled, and sexual assaults had gone up fourfold. At the same time, there was a shortage of counseling personnel. The shortage resulted in a long waiting list, an overloaded counseling staff, and a tendency to dispose of the students by prescribing psychiatric drugs. Many cases escalated from anxiety to suicidal tendency when professional helps could not be made available in time. Anxiety-generated behavior problems were often misdiagnosed as the attention deficit disorder and were quickly swept under the carpet [48]. Countless pills of Ritalin (methylphenidate) were shoved down students' reluctant throat. This widespread practice

transformed school health offices into the biggest legalized drug pushers ever. It is hard-pressed to expect the students to be able to “kick the habit,” after they eventually outgrow their juvenile problems.

The problem of grade inflation was unmistakably real. About 5 or 6 years ago, I began to witness the arrival of a new breed of college graduates, who seemed to retain so little of what they had learned in college and in high school, as if, in the words of a candid student, “[they] had never taken the course before,” in spite of high attained grades. With such a background, it is almost impossible for them to understand the course materials, unless the teachers made a special effort to re-teach high school topics, such as physics, in a highly abbreviated fashion. The increasingly common practice of tying student evaluations to teachers’ merit raise also took its toll. Rumor had it that some teachers deliberately leaked the test questions to students in order to shore up students’ grade performance so as to win good student evaluations. This behavior was exactly what Deci’s theory had predicted.

In recent years, I observed a trend that was even scarier and more intractable than grade inflation. Our “B” students seemed to be better equipped to solve novel problems than “A” students, hence the term “dumb high-achievers.” *Grade inversion* is certainly more difficult to neutralize than grade inflation (some college admission officers cleverly combated grade inflation by “renormalize” the test scores of individual high schools on the basis of their alumni’s past performance). However, according to a graduate student, her father, a mid-level executive of a Detroit automobile company, had quickly learned to set the preference of new hires on “B” college graduates instead of “A” college graduates, because “[the latter] could not perform trouble-shooting but [the former] could.”

Was the K-12 teachers’ union the true culprit of “the rising tide of mediocrity”? The K-12 vs. higher education dichotomy offered a convenient correlation. But correlation does not always suggest causation, as pointed out earlier in Sec. VI. In view of the harmful effect of flawed educational psychology, perhaps there were other hidden factors. Another valid correlation suggests the following. The educational doctrine propounded in Lawson’s book affected primarily K-12 teachers trained in a traditional teachers college. Few, if any, of college and university professors had the benefit of this type of formal training. Rather, most university teachers were trained “on the job.” In other words, professors based their teaching approaches on their own intuitive feeling and they were allowed to explore and stumble. As expected, college and university teaching styles are rather heterogeneous and the quality of teaching varied widely. That is not to say, K-12 teachers were uniformly unsatisfactory. Strangely, some students managed to learn in spite of their teachers. So did some teachers managed to do it right in spite of the experts’ recommendation and indoctrination. It was just that the relative lack of constraints allowed more non-conformist teachers to survive in colleges and universities. Ironically, the

lack of formal teachers training miraculously spared college and university professors the assault of erroneous doctrines. This may explain why American universities were able to maintain a reasonably high standard in the previous century. However, the signs of erosion began to surface because of the continuing deterioration of the K-12 system. Now, the adverse effects of rule-based learning can no longer be swept under the carpet. Pretty soon, mediocrity may show up in research since graduate students often play a vital role in university-sponsored research. They do not just offer a pair of convenient hands in the laboratory.

Apparently, all the past educational reforms seemed to have missed the primary and more fundamental factors. It is about time to deal with these hidden factors. Or, maybe they were not so hidden if only we recognize the connection between creativity and learning. In fact, the key insights were laid down about 100 years ago. The publication of Poincaré’s 1908 book provided an enormous amount of insights, about the cognitive aspect of creativity and learning, but, regrettably, his “opinions” were largely ignored. Yerkes and Dodson’s 1908 article covered the psychosocial aspect of creativity and learning. The latter principle allows us to put “two and two together.” The rise of students’ test scores coincided with the increased incidence of psychological problems, and the Yerkes-Dodson law provided the causal link. Then came Lawson’s flawed theory, which glorifies the value of vast knowledge, thus completing the links of a vicious cycle. Of course, we have reason to doubt whether Lawson’s theory was the cause or the effect of “the rising tide of mediocrity.” Nevertheless, the conclusion is the same: Lawson’s theory is part of the problem rather than part of the solution.

A new danger lurking beyond the horizon is the recently popular buzzword of “knowledge-based economy.” The excessive emphasis on knowledge at the expense of students’ cognitive skills will, ironically, defeat the goal: knowledge without the accompanying skill to use it cannot drive a sound economy. Even Einstein said, “Imagination is more important than knowledge.” However, schools continued to act like wholesales distributors of knowledge; the cognitive skills to utilize acquired knowledge seldom appeared in the list of priority. A significant fraction of biomedical students felt overwhelmed by the amount of detailed knowledge to be “learned,” but the relief is nowhere in sight. Biomedical sciences happened to be at the epicenter of information explosion. In the public perception, a medical doctor is expected to command an ever-increasing amount of up-to-date knowledge. Ignorance conjures up a specter of quackery but inability to reason rationally was seldom regarded as a sign of professional incompetence and a threat to patients’ well being.

Actually, back in 1966, West [49] already warned about it and pointed out that most knowledge transferred to medical students in school will either become obsolete or forgotten, by the time they practice medicine. It is even more so today in view of ever-accelerating information explosion. Few people can

remember, for a long time, factual information acquired by means of purely rote memorization, if they use it only once at the time of testing. However, clinicians have no trouble remembering this type of knowledge without much effort if they use it routinely on a daily basis. What we can do now is reduce the amount of information to be “taught,” concentrate on elucidating principles, and teach students primarily to enable them to learn on their own once they leave school.

In addition, the educational community, once misled by experts, must take a second look at the value of picture-based learning. Our own experience indicated that practicing picture-based learning would not significantly compromise the acquisition of factual knowledge. What it lacks in enabling the acquisition of a large amount of factual knowledge, the approach makes up for by making it easier to remember integrated factual knowledge and by prolonging its retention, not to mention that the absence of stress also enhances learning and that picture-based reasoning enables one to utilize acquired knowledge efficiently and effectively. It seems to be an effective way to break the vicious cycle, generated by information explosion and fierce competition.

Speaking about picture-based learning, the popular teaching approach by means of custom-tailoring instructions to students’ “learning styles” deserves a comment. Students are classified as visual (or global) learners, auditory (or analytic) learners, which roughly correspond to practitioners of picture-based learning and rule-based learning, respectively, plus “tactile” and “kinesthetic” learners. Superficially, it seems to make sense, and it is even politically correct to leave students’ learning styles alone and to cater to their individual needs. What was not generally recognized is that an auditory learner could be trained to become a visual learner. As discussed in this article, leaving auditory learners alone without intervention forever condemns these students to a perpetual handicap in reasoning. In reality, there was no evidence that the learning style approach actually worked, according to an article by Stahl [50].

In recent years, instead of doing what should have been done, policy makers decided to make public schools accountable in an effort to reverse the trend of deterioration of public education. Students’ grade performance is now tied to funding in the so-called No Child Left Behind Act. Yerkes-Dodson law and the research of Deci’s group predicted that the situation would get worse, as some schools began to teach just for testing. Fortunately, objections to teaching just for testing and concrete suggestions to combat this problem began to surface [51,52].

There is a lingering question: If the theory advocated by educational psychologists is so wrong, do we need to thoroughly revamp teachers’ education? Could the cure be worse than the disease? Fortunately, a radical restructuring of teachers’ education may neither be necessary nor desirable. All one needs to do in implementing these teaching methods is add the instruction of visual thinking, which may significantly increase the success rate of traditional teaching approaches,

such as small group teaching and cooperative learning. It is likely that these empirically derived methods may well continue to flourish in the absence of constraints imposed by a dysfunctional theory.

It is much harder, however, to alter the student culture of grade-driven learning. It is also politically difficult to undo the performance-driven accountability, which the public seemed to expect. A less disruptive strategy is to turn the trend to our advantage. This means: criteria of student performance have to change. In the past, standardized testing worked well and the grades so obtained also reflected students’ learning with reasonable accuracy. However, as Hans Sachs in *Die Meistersinger von Nürnberg* suggested, it is wise to “test the rules [i.e., criteria] themselves once [in a while] to see whether in the dull course of habit their strength and life doesn’t get lost and whether [we] are still on the right track with nature.” It was the marriage between standardized testing and rule-based learning that doomed the time-honored testing method. However, we do not have to go as far as outlawing standardized testing. If we simply added a small fraction (e.g., 5 to 10 %) of thought-provoking and insight-demanding essay questions, few, if any, of the highly motivated students would be willing to forfeit the essay points. That alone might change their learning behavior. Likewise, that alone might discourage teachers’ behavior of teaching just for testing. This less-than-radical reform has a better chance of enlisting support of college and university professors than a total elimination of standardized testing.

Last but not least, we must realize that exposing the fallacies of Lawson’s theory is not merely of academic interest. It is an imperative to halt the continuing path towards the demise of public education and perhaps also the destruction of civilization. By identifying background knowledge as the only source of inspiration and by advocating the acquisition of a vast amount of knowledge, Lawson’s theory would serve as the scientific justification of shoving an increasing amount of knowledge down students’ reluctant throat. With the ever-accelerating information explosion and the emphasis on knowledge-based economy, students would never have time to think or learn to think. Implementing Lawson’s theory would cripple students’ critical thinking, thus further exacerbating the casualty of information explosion. Lawson’s theory has the potential of driving us back to the Dark Age. It is one thing merely to craft a defective theory, because it usually does not cause an enduring harm as long as critical thinking still prevails in the citizenry. It is yet another thing to champion a dysfunctional educational approach that is so potent as to produce future generations that are by and large devoid of ability of critical thinking, thus dashing human’s ultimate hope of self-correction. It is, therefore, not an exaggeration to regard Lawson’s theory as one of the greatest threats to civilization. We have witnessed, at the beginning part of the 21st century, the triumphant return of irrationality, resulting in many harmful environmental policies, exacerbating politicization of

science and science policies, and financial crisis and worldwide recession. It is a consolation that the enigma of human creativity was elucidated just in time of need. After all, self-preservation is a difficult problem to solve. Human's collective wisdom must then rise to the occasion. Speaking about collective wisdom, we are thus brought back to square one: education. However, education is a double-edged sword. Education, intended for enlightenment, accomplishes its task primarily by enlightening the mind. However, it can also shape the mind in the opposite way: dumbing down. Regrettably, in spite of good intention, research in educational psychology went terribly awry at the turn of the century. In hindsight, the investigators should have figured out how humans achieve high creativity before settling on a half-baked but erroneous theory. However, it is better late than never. Although it has already been a hundred years over due, it is not too late to incorporate the insights gained through the work of Poincaré and that of Yerkes and Dodson in future educational reforms. After all, collective wisdom can only be accumulated and sustained by means of sound education of the general public.

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