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OUR FAILING SCHOOL SYSTEMS

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INTRODUCTION

This article aims at initiating a debate on the future of K-12 school education, which has undergone slow changes over the past 200 years, but is now at a dire existential crossroad from which it may not easily recover. This section provides an overview of the article – the summary statements are discussed in the sections that follow.

The current education system in each State of the Union is constrained, (1) by how school curricula is determined by a small, top-down group in the Board of Education, (2) an inclusion of too much material requiring rote learning, (3) poor quality, inadequately trained teachers, and (4) success defined by very high marks in yearend examinations conducted by State Education Boards. This results in schools preparing or, rather, training students for such final examinations, with much cramming aimed at likely questions. As a result, true education – training the mind to think or, equivalently, developing the ability to think critically – is a casualty. So, the system is mainly producing ‘worker bees’, that can do ‘routine tasks’, but innovation is a big loser. While considered as being merit-based, this system essentially measures the amount of material crammed and, therefore, lowers the overall standards of education.

Furthermore, in the current system, the time for instituting curricular change – including content definition, text-book preparation, and teacher training – is at least a decade. While this was acceptable in the past, when societal needs changed slowly, exponential changes in knowledge technologies are now outpacing the ability of the current system to respond with timely curricular changes and teaching methods. As a result, the current school systems are in danger of becoming irrelevant.

Organized school education for large numbers of students is a relatively recent societal innovation. In the nineteenth century, school education in western countries mainly comprised learning Latin, Classical Greek, Arithmetic, and Euclid’s geometry – with an emphasis on rote learning. Major changes occurred somewhat slowly in the twentieth century: First Classical Greek was excised from the curriculum but, to understand English better, Latin continued as a compulsory subject – again with an emphasis on rote learning. Science was added, as were social science, fine arts, and music, and the importance of participation in sports for team development was recognized. Now, aspects of computer science with internet connectivity have become an important adjunct to the curriculum.

With the availability of handheld phones on which calculators can be used for carrying out routine arithmetical operations, such as multiplication, memorizing multiplication tables has become unnecessary – calculators can be used in classrooms and in examinations. But, although search engines such as Google have made possible ‘instant’ access to information on any topic on computers and smart phones – thereby obviating the need for memorizing large chunks of facts and history – the current school systems still require the unnecessary cramming of too much material. It appears that powerful ‘curricular czars’ in School Boards are oblivious to how easily facts can be recovered via the internet. Moreover, each member of committees charged with designing curricula wants his/her ‘important’ material included. At the very least, with the wide availability of internet-based search engines, the Boards could have reduced the ‘cramming load’ on students, freeing more time for acquiring critical thinking or analytical skills, which do not become obsolete.

After many years of research, the availability of massive computational resources has made it possible to train neural networks on vast amounts of data – such as, for example, all newspaper articles, books by authors, … – so that Artificial Intelligence (AI) tools, such as ChatGPT, can produce detailed answers to typed queries in a matter of seconds. Given a few inputs, such as, “What is the significance of revolutionary wars," will generate a very cogent writeup on that topic within seconds. Educationists feel threatened: "Students will no longer do homework; they will just have ChatGPT produce writeups." But, just as the initial resistance to allowing the use of calculators in class and examinations fell on the wayside – making rote learning of multiplication tables obsolete – AI tools are here to stay. And education systems and methodologies must enable students to make use of such tools, freeing up more time for critical thinking and innovation.

While advances in technology in the past helped amplify the capabilities of humans at ever increasing rates – bullocks, horses, and mules provided power to till larger portions of farms, as well as means for transportation; stream engines not only made industrial production possible, but led to robust means for transportation of humans and goods; electricity made possible lighting, motors for pumping water for irrigation; electronics made possible radio and television communications, aircraft revolutionized travel, and computers enhanced the ability to compute, the internet provided instant means for communications, and smart phones brought all means of instant communication to hand held devices – AI already is able to carry out human, 'brain-like' functions at lightning speeds. For the first time, it offers the potential for doing *independent*, 'critical thinking' tasks: in contrast to earlier technologies that enhanced what humans can do, AI can potentially do what humans in principle are not capable of doing. If not properly controlled, AI could take over the cognitive functions of the brain – essentially replacing humans.

Certainly, the current top-down, Education-Boards do not have the expertise to react to changes occurring at exponential rates. While details of the different elements of the education system will be discussed in the sections that follow, to understand how rapid exponential changes can be, consider the following apocryphal story: It relates to the 64 squares on a chess board – the game *Shatranj*, said to have been invented in India. The story goes that a king wanting to reward someone who saved his life averred, "Ask whatever you want, and I will give it to you." The man said, "Oh king, place one grain of rice on the first square on a *Shatranj* board, then two grains on the second square, four grains on the third square, eight on the fourth square – just keep doubling the number of grains from one square to the next. All I want is the rice on the 64^{th} square." The king was very upset at being asked so trivial an amount. Based on our linear thinking, no matter how 'wild' our estimate, it's almost impossible to guess the final answer: It works out to about 230 billion metric tons of rice – about 230 times the World's current annual rice production of about one billion metric tons!

While the rate of change has so far not reached this extreme, it's already beyond levels that the State Boards can keep up with. As a result, the school curricula and teaching paradigms will guarantee rapid obsolescence of the entire school system, making them irrelevant relics. Conversations, or noises, about digitization essentially consist of 'computerization' and 'distant learning' aspects of the current outmoded system and, therefore, lull educationists into believing that they can handle the rapid changes in the offing. They need to prepare an education system for the model problem in which what we learn today will become obsolete tomorrow.

What is required is *ab initio* look at the entire K-12 education system that bypasses the existing, almost petrified system. An effective model, that helped modernize the failing technical education system, is provided by the creation of the first four, *greenfield* autonomous IITs: Create many independent, well-funded *autonomous* K-12 schools mandated to create new educational paradigms, and empowered to award their own high-school diplomas. From such multiple "laboratories" may emerge new education models that could serve us well into the future.

The sequel analyzes various aspects of education and makes the case for many autonomous schools that develop original educational paradigms for the rapidly changing intellectual environment, appropriate curricula, and knowledge imparting systems.

SOME IMPORTANT LESSONS FROM HISTORY

The most important lessons from history, relevant to the education enterprise, are, first, that knowledge and innovation grow in open systems where large numbers of people are free to express their views. Top-down dictatorial systems in which a few people make all the decisions – like the current education systems – stifle thought and innovation, resulting in stagnation. As such, the concept of one or several centralized, 'national curricula' is, clearly, a retrogressive idea. And, second, that the knowledge generation rate increases with time; eventually this can overwhelm our ability to cope with such changes.

In support of these contentions, this section presents a detailed tour of the changes in our understanding over millennia – finally pointing to what we are in for in the near future.

Long ago, life was very tough. Our early ancestors were concerned with the 'mother of all knowledge issues', life and death, which have concerned mankind throughout history. With carnivorous predators, life could be short. This resulted in the first major, technological advance – increasing life by living in caves – and the subsequent quest for immortality.

During the very early years of mankind knowledge grew slowly. First, man had to learn to survive. Food was important but it took thousands of years to learn to grow it, which, until the last few centuries was based on empirical knowledge.

In the very early years, a lack of understanding of the environment and fear of natural forces resulted in man creating many gods and myths about such forces, remnants of which still affect the outlooks of large swaths of people. Once man became comfortable, his focus shifted to where he had come from, resulting in many unsubstantiated theories, or myths. And, of course, he did not want to die.

The Pharaonic Era (3,000-323 BC). Fast forwarding to ancient Egypt, the main concerns of the Pharaohs was to expand and consolidate their empire, lead a good life, and to not die. By this time, they had learned that no amount of effort, including sacrifices to the many gods, could prevent eventual death. So, the priests concocted an elaborate theoretical structure in support of an 'afterlife'; the Pharaohs would not die, instead they would lead a more comfortable afterlife, which required the building of large mausoleums – the pyramids – for interning bodies for the onward journey to the afterlife. To assure ample comfort, food and wine, jewelry, and slaughtered slaves and artefacts, such as boats, were buried along with the Pharaoh to sustain him in his afterlife.

Of course, a critical part of this process was an afterlife model, which called for preserving the body: During the embalming process, the vital organs – such as the heart, the liver, and the lungs – which could not be embalmed, were removed and placed in four stone urns at the corners of the stone sarcophagus. And, since it was well established that the brain was a useless organ, it was scraped out with copper hooks pushed through the nasal cavity and thrown out! Also, knowing that the earth was flat was used to chart an optimum course for the ship carrying the Pharaoh into afterlife.

Everybody, except a few were happy: The Pharaohs successfully travelled to the afterlife, never returning to create problems for the current Pharaoh, and the priests and their assistants were promoted. The exception was the poor workers who had to build the pyramids.

However, in this top-down, dictatorial system, in which all 'knowledge' flowed from the top down, the dictums of the Pharaoh's could not be questioned. The sole source of wisdom was the Pharaoh, who regarded the brain as a useless organ – resulting in very limited progress on a millennial timescale during the long Pharaonic era.

Classical Ancient Greece (480-323 BC). Fast forward to the heydays of the Greek civilization, in which, in circa 508 BC, the city state of Athens came up with the crazy notions of democracy and free speech. These revolutionary changes enabled everyone – as long as they were not slaves – to contribute ideas; but this freedom to speak was somewhat tempered – because of his 'dangerous' ideas, and their possible effect on the young, Socrates had to commit suicide by drinking hemlock.

In this democratic environment, many Greek philosophers developed theories that are still studied: Socrates (470-399 BC), his pupil Plato (died circa 347 BC), and his pupil Aristotle (384-322 BC) laid the foundations of logic and political philosophy. Euclid (circa 305-282 BC) set geometry on an axiomatic foundation; his axiomatic treatment of geometry is still taught in schools. Archimedes (circa 287-212 BC), a mathematician, physicist, engineer, astronomer, and inventor is regarded as one of the leading scientists in classical antiquity, and as the greatest ancient mathematician, and even as one of the greatest of all time. And the philosopher and physician Hippocrates (460-370 BC), laid the foundations for medicine – faulty ideas of which, unfortunately, still drive the practice of Yunani (Greek) medicine in many countries.

In just about 250 years (circa 470-212 BC) this small group of Greeks created axiomatic geometry, philosophy, politics, the music scale, recognized that the earth was round and estimated its diameter, etc. The time scale for change was reduced from millennia to less than a century.

Middle, or Dark Ages (500-1500 AD). While the Greeks may have eventually improved such models, civilization again began to change for the worse: With the decline of the Roman Empire, Europe was overrun by the development and enforcement of religious dogma. As in the days of the Pharaohs, all knowledge and decision-making power was vested in a small, but elite, religious leadership team headed by the Pope. The growth of innovation came to a stop. Freedom of thought introduced by the Greeks was reversed. And, of course, the world again became flat.

Towards the end of this dark era, the very versatile Da Vinci (1452-1519) made major contributions to art, anatomy, and mechanical devices; based on autopsies and dissections, at age twenty-eight, Vesalius (1514-1546) published a revolutionary treatise on anatomy; and Copernicus (1473-1543), Galileo (1546-1642), and Kepler (1571-1643) laid the foundations for astronomy. William Harvey (1578-1657) proved that blood was pumped around the body in a closed system. During these dark ages, free-speech rights were suspended – innovators could be burned alive at the stake – even Galileo had to be careful about what he said.

The Renaissance (1600-1900 AD). The intellectual environment improved during the Renaissance, when freedom of speech again began to emerge. Rather than focusing on afterlife, the study of nature became important. The world again became round. The study of anatomy progressed rapidly. Books became accessible to more and more people, and the knowledge base and knowledge generation became more widely dispersed.

The seventeenth century, called the 'Age of the Scientific Revolution', was a major epoch in the history of science. Instead of focusing on *how* things (facts) are, scientists turned to *why* things (reasons) happen – a shift from speculation to experimentation. Interpretations became mechanistic, and the language of science became mathematical.

Over a 200-year period, about 1600-1800 AD, major strides were made in mathematics – by Descartes (1596-1650), Newton (1643-1727), Leibnitz (1646-1716), and Euler (1707-1783) – which were continued well into the 19th Century by Gauss (1777-1855), Lagrange (1736-1813), Cauchy (1789-1857), Riemann (1826-1866), Hamilton (1805-1865), Cayley (1821-1895), and Poincare (1854-1912). These advances in mathematics over a 300-year period laid the foundation for the future rapid advances in physics.

In addition to making significant contributions to mathematics and physics, Newton's theory of gravitation (1687) was an epochal advance in physics: While it quantitatively explained planetary motion and other gravitational phenomenon, it was based on the notion of 'action at a distance' – an abstract idea of two far-away bodies attracting each other without an intervening medium. This has to be the single greatest advance in physics – still largely valid – until the electromagnetic theory of Maxwell (1831-1879) unified electricity and magnetism, which required the mathematical structure developed in the previous 200 years.

The foundations of modern biology have its roots in the 19th century: The seminal work defining this era was the publication in 1859 of "On the Origin of Species" by Darwin (1809-1882). By experiments on pea-plant cross-breeding during 1856-1863, Mendel (1822-1884) established rules of heredity, thereby laying the foundations for genetics. Later, Pasteur (1822-1895) discovered that microorganisms cause fermentation and disease, and developed vaccines for anthrax and rabies. The bacteriologist Koch (1843-1910) discovered that anthrax, septicemia, tuberculosis and cholera are caused by bacteria. Due to their efforts, by the end of the 19th century different types of microorganisms had been recognized as causing disease. In 1842, Long (1815-1878) performed the first painless operation by using ether as an anesthetic. The anesthetic property of chloroform on humans was demonstrated by Simpson (1811-1870) in1847. Semmelweis (1818-1865) and Lister (1827-1912) introduced antisepsis into medical practice; which significantly improved the outcome of operations.

Advances in Technology. In 1712, Newcomen (1664-1729) invented the first atmospheric-pressure steam engine for pumping water from coal mines. The invention of the high-pressure steam engine, patented in 1769 by James Watt (1736-1819), which converted the reciprocating motion of a piston to more usable rotary motion, resulted in the First Industrial Revolution (circa 1760-1830): Automation of the textile industry; iron production processes; machine tools, developed circa 1800-1850, made large-scale manufacture of metal parts possible; manufacturing interchangeable parts for muzzle-loading muskets in 1798 by Whitney initiated the era of mass-produced parts. The first (steam-engine-driven) railway was introduced in 1825. The telegraph, invented circa 1840, provided the first long-distance communication system.

After a slowdown, starting in about 1870 a new group of innovations resulted in rapid changes – called the Second Industrial Revolution (1870-1914) – that were driven by major advances in science and mass production: enormous expansion of rail and telegraph lines. Telephones (1876) and electrical power (1882) had enormous effects on society: The first incandescent electrical bulb was demonstrated by Edison (1847-1931) in 1879, and commercial distribution of electric power for lighting started in 1882.

The Twentieth Century. Physics was in a state of flux at the end of the 19th Century: First, to explain black body radiation, Max Planck (1858-1947) assumed that energy travels in discrete packets, called quanta, rather than by continuous waves. Bohr (1885-1962) used this concept to develop a model for the atom that explained radiation spectra. This eventually led to the foundation of Quantum Mechanics – a *nonintuitive*, probabilistic theory – by Schrödinger (1887-1961), Heisenberg (1901-1976), and Dirac (1902-1984). Second, questioning issues relating to the speed of light through a 'fictitious' medium called ether led Einstein (1879-1955) to his Special theory of Relativity (1905), and eventually to his General Theory of Relativity (1915).

Quantum Mechanics and Relativity, both involving very revolutionary ideas, dominated the first quarter of this century; both had marked effects on subsequent developments in physics – such as nuclear physics, elementary particles, quantum electrodynamics, and string theory. Also, quantum mechanics influenced developments in chemistry, and thereby in biology.

In a seminal 1931 paper, Gödel (1906-1978) published two incompleteness theorems of mathematical logic regarding the limits of provability in axiomatic theories. This completely changed the direction of work on the foundations of mathematics by giants such as Frege (1848-1925), Russel (1872-1970), and Hilbert (1862-1943).

Although the study of biology had been undergoing a change, the seminal 1953 paper by Watson (1928-) and Crick (1916-2004), in which they characterized the double-helix structure of DNA, changed the emphasis towards molecular biology, which deals with all elements concerned with biological processes essential for the functioning of cells. This mid-century discovery elevated foundational aspects of biology to a major frontier of science.

The first cloned mammal, a female sheep, Dolly, born on 5 July 1996, had three mothers, of which one provided the egg, another the DNA, and a third carried the cloned embryo to term.

Through his work on generative grammar in the mid-1950s, Chomsky (1928-) totally revolutionized linguistics. He also changed the paradigm for how languages are acquired by arguing that human brains come innately equipped with the rules for language acquisition that get refined as humans grow.

Medical therapeutics grew rapidly with the discovery of antibacterial sulfa drugs (1930s), Penicillin (1928-1945), and Streptomycin (1943), with many more potent antibiotics in the pipeline. The first antivirals were discovered in the 1960s, with rapid growth in the numbers now available.

While the affairs the mind have concerned mankind from the beginning, 'abnormal' or psychotic behavior in the past had been attributed to (1) demons, spirits, and the displeasure of gods – still prevalent in many societies, with cures requiring beatings to drive out spirits and demons, (2) brain damage, inherited or through trauma, and (3) emotional stress to an otherwise normally functioning mind – which led to psychoanalysis as the basis for cure, as practiced by Freud and Jung, for example. Without an adequate scientific understanding of the functioning of the brain, the now discredited treatments such as insulin and electrical-shock therapies and lobotomies continued till the middle of the 20th century. Modern psychiatry began in the 1950s with the discovery of the therapeutic effects of Chlorpromazine (Thorazine, Largactil) for schizophrenia and other disorders, and lithium carbonate (Lithium) for bipolar disorder. Now many other antipsychotic drugs are available.

Advances in Technology. Beginning with Röntgen's discovery in 1895, X-ray technology developed into a one of the most powerful medical diagnostic tools in the 20th Century, spawning among others, important technologies such as CT Scanning (1972), and MRI Scanning (1980s).

Vacuum-tube driven radios evolved circa 1910-1930, followed by television circa 1930-1940. Special microwave tubes developed circa 1940 made radar possible. The first transistor, a solid-state device, was invented in 1947 by Bardeen, Brattain, and Shockley. Soon thereafter transistors began to replace vacuum tubes, thereby revolutionizing the field of electronics. It made possible smaller and cheaper radios, calculators, computers, and other electronic devices.

The ENIAC (Electronic Numerical Integrator and Computer) – the first programmable, electronic, general-purpose digital computer – was completed in 1945. A later version of this building-sized machine had approximately 18,000 vacuum tubes, 7,000 crystal diodes, 1,500 relays, 70,000 resistors, 10,000 capacitors, and approximately 5,000,000 hand-soldered joints; it weighed more than 30 metric tons! Although this machine was later used for atomic-bomb related work, it was developed for the US army to calculate cannon-shell trajectories.

With the invention of the transistor, bigger and faster computers were developed mainly for scientific and data-processing applications: Large, ‘main-frame’ computers; smaller, modular (DEC) machines, (SUN) work-stations; and desk-top machines – miniaturized electronics resulting in smaller and faster machines.

The demands of manned space flights accelerated electronics miniaturization, integrated circuits, and chips with enormous number of logical devices and interconnections that now make possible computers, ubiquitous computer-controlled devices – such as those used in automobiles – and cell phones. The number of transistors on a chip has increased from thousands in the 1970s to billions now.

In a flurry of activities several companies came out with early versions of home computers. Notable were the first home computer, the Apple1 introduced in1976, the Apple 2 – the first machine with a graphics user interface (GUI) – in 1977, followed by the very successful Macintosh in 1984. Other notable machines, which set standards for personal computers were the IBM PC (1981) – with 16-256 KB DRAM – and the IBM PC/AT (1984) – with 256-512 KB DRAM and a 20 MB hard drive.

Several, somewhat heavy portable computers entered the market early: Osborne 1 (1981) and Compaq Portable (1982), the first PC-compatible portable computers, were followed by many smaller more powerful portables. The Apple PowerBook (1991), set the present de facto standards for laptops, including a palm rest. Also noteworthy is the IBM ThinkPad (1992).

Starting with Windows 1.01 introduced in 1985, the Microsoft Windows operating systems rapidly evolved into dominant, ubiquitous operating systems for Personal Computers (PCs). And, with the introduction of Word (1983), Excel (1985), and PowerPoint (1987), Microsoft Office, first introduced in 1990, offers the dominant solution for office software.

Since their invention in 1960, lasers are now used in a wide variety of applications: consumer electronics, information technology, science, medicine, industry, law enforcement, entertainment, and the military. Fiber-optic communication using lasers is key to modern communications, including the Internet. Some key everyday applications – barcode scanners (1974), laserdisc players (1978), compact disc players (1982), and laser printers for the commercial market (1984).

Research on communications between computers in the 1970s, followed by funding by US government agencies in the 1980s, resulted in the availability of open internet connections by the mid-1990s. The World Wide Web, a global information medium accessible through computers connected to the Internet, was invented in 1989. Intense competition among early browsers – software for searching information on the web – such as Netscape and Internet Explorer ended up with two dominant browsers: Chrome by Google and Microsoft Edge.

Cordless phones – with analog wireless connectivity between a handset and a land-line base – became widely used in the early 1980s. In the 1990s, new cordless phones in the 900 MHz frequency range provided better audio quality with signals that could penetrate walls. Digital signals allowed the phones to be more secure.

The first commercial handheld mobile (wireless) phone, the Motorola DynaTAC 8000X, was introduced in 1983. These phones had antennas for receiving/transmitting the lower frequency signals (824–849 MHz for downlink and 869–894 MHz for uplink). Second-generation (2G) digital cellular technology was launched in 1991. Short Message Service (SMS) technology was introduced in 1992. The first BlackBerry phone with email capability was introduced in 1999.

The launch of the Google Search engine in 1998 – which eventually become the most used web-based search engine – first made possible searching for meaning of words, like an extended dictionary, and then searching for detailed information on topics. Just as electronic calculators made memorization of multiplication tables unnecessary and obsolete, so search engines made memorization of ‘facts,’ a large part of current school curricula, obsolete.

The period beginning in the mid-20th century – during which technology changed from mechanical and analogue electronics to digital – is variously referred to as the Third Industrial Revolution, the Information Age, and the Digital Revolution.

Obsolescence Rates. As an example of rapid obsolescence, a study commissioned by the American Society of Mechanical Engineers on the Centennial of its founding in 1998 pointed out that the half-life of Mechanical Engineering education was about five years. In the quarter century since then the half-life will have become much lower. Note that mechanical engineering education did not change much from 1900 to the 1950s, after which there was a major shift from machine-oriented to an engineering science-based curriculum.; and it’s this newer curriculum that was being outdated. The rate of obsolescence in areas such as computer science is much higher. For over a decade now, technology changes are so rapid that not constantly keeping up with the changes leaves one behind.

The Twenty-First Century. The launch of the Google Search engine in 1998 set the stage for the rapid digitization of many processes we now take for granted: Wikipedia, the free-content online encyclopedia (2001), Google News (2002), Gmail (2004), Facebook (2004), Google Maps (2005), YouTube (2005), Twitter (2006), iPhone (2007), Google Chrome (2008), WhatsApp (2009), Instagram (2010), Snapchat (2011), and TikTok (2016). The effectiveness ('democratization') of all new social media was made possible by the invention of the first smart phone, the iPhone, a multimedia communication device that gives *instant* access to, and dissemination of, all types of information.

YouTube went well beyond the ability of Google Search for detailed information on any topic by providing videos on 'all' conceivable topics: 'How to' videos have revolutionized self-helpers with easy instructions on repairs, 'how' things work, lectures and podcasts on all topics at all levels, news, music videos, …. And smart phones have made all this information instantaneously available on one efficient, multimedia device.

The launch of ChatGPT in November 2022 may be used to mark the new era of Artificial Intelligence (AI), in which digital devices or AI Software are expected to surpass the capabilities of human intelligence.

What Next? With tools such as CRISPR, it is now possible to edit DNA to remove or add functionality to humans at the egg, sperm, and embryo stages – subject to ethical considerations, allowing for 'custom-designed' humans in whom disease genes have been removed and additional desirable functionalities added. The creation of artificial wombs – which should now be technologically feasible – will make possible the continuation of humans without the normal sexual processes.

Brain chip implants connected to computers that control external body action purely by thought have already been demonstrated. Again, subject to ethical considerations, chips embedded in the brain could be used to enhance brain functions such as memory and thinking ability. In conjunction with AI, the proper use of such technologies could enhance the 'IQs' of normal persons to 'genius' levels. Just as the now ubiquitous spectacles and hearing aids are used to compensate for visual and hearing impairments, brain-implanted chips could be used to make up, or even enhance, brain functions, thereby providing means for AI to be a supportive aid rather than a competitor. But the misuse of such technologies could have disastrous consequences.

One thing is certain: We are now on the verge of an era of frighteningly rapid change. Whether we can adjust to such rapid changes will partly depend on whether our education system adequately prepares us for them.

Summary. Two very important lessons from the history of the past five millennia: First, knowledge and innovation grow rapidly in a 'bottoms-up' system, such as in a democracy, where large numbers of people have the freedom to express their ideas; conversely, innovation is stifled in 'top-down' dictatorial systems in which few people determine what is best for everyone else – this results in particularly bad outcomes in rapidly changing environments. Second, the rate of obsolescence of 'knowledge' has been increasing rapidly, mainly due to the rapid increase in the very large numbers of educated persons involved in research and innovation. Eventually, this rate may exceed the assimilation rate of humans for new ideas; education systems must be designed to remain current in such environments.

In principle, advances just in the first decade of this century have made it possible for over four billion humans to 'instantaneously' access details of events anywhere in the world, to have their opinions and comments made available to anyone everywhere, and to form opinions based on such rapidly propagating 'raw information' that has neither been vetted for authenticity nor for accuracy. Rather than such instant communication resulting in an informed, open society, it balkanizes society into large groups that believe in similar 'conspiracy' theories without any foundation – and it is such groups that will decide the political futures of nations! As such, agencies that can learn to influence people into believing the 'right' fiction will control the world.

Contrast this with communication technologies just a few centuries back when information travelled very slowly, allowing time to vet ideas and to evaluate their effects on society, and few enlightened leaders could use this information to better society. But, of course, as history has shown us, unsavory dictators can use propaganda to gain power by 'legitimate' democratic means. In the future, even with democracy, enormous amounts of unvetted, 'influenced' information available to all could cause political chaos.

EVOLUTION OF THE K-12 EDUCATION SYSTEM & MASS LITERACY

For the longest time, most humans were only concerned with manual agriculture – essentially with producing food; literacy and education were not necessary.

With the growth of Christianity, reproduction of the Bible and commentaries thereon were painstakingly hand-copied by monks in abbeys. It was a slow, tedious process that did produce beautiful, handwritten and illuminated bibles. Later, copies of nonreligious books were also reproduced by hand.

Gutenberg's invention of the printing press first made Bibles (in the mid-1450s) more easily available. Then, with advances in printing technology, the availability of books and newspapers made literacy a desirable skill.

Although formal schools for imparting structured education – mainly comprising Latin, Classical Greek, arithmetic, geometry, and theology – were available to the elite few in the 18th century, mass education was initiated in the mid-19th century by the need of the industrial age for more skilled workers.

In the 20th Century, with increasing populations and prosperity resulting from rapid industrialization, the number of students in schools grew continuously. As a result, high-school education has become one of the largest enterprises in the world, catering to hordes of students. And, borrowing from standardization in industry, the school systems have become highly organized standardized systems in which creativity is a casualty.

The current, top-down Boards-of-Education systems offer standardized curricula and uniform examinations that, in principle, provide a fair equitable platform for all students. But this system is designed to reward those good at cramming large amounts of facts measured by marks – it neither measures the true capabilities of students nor their intellectual and academic standing; the ability to analyze new data, or critical thinking, is a casualty. As a result, this system produces non-innovative worker-bees. And, while this system might appear fair, it really is not: students who attend better funded and better staffed schools, and have access to the burgeoning 'coaching' industry, have an unfair advantage over bulk of those coming from poorly staffed government-run schools that cater to most students.

We are entering an era of *unprecedented* change – approaching exponential change – which those used to very slow linear changes cannot easily comprehend. A familiar, although much slower example of nonlinear change is the difference between simple and compound interest for the growth of money deposited in banks. And when you combine this with the huge, somewhat frightening changes that artificial intelligence (AI) will cause, our moribund education system will continually leave us behind.

It isn't as if other educational systems haven't been explored: The Montessori method of teaching, developed by Dr. Maria Montessori in the early 1900s, is child-centered; it involves child-led activities in classrooms, with children of varying ages, in which teachers encourage independence among the students. It is based on a model of human development, in which (1) psychological self-construction in children and developing adults occurs through environmental interactions, and (2) they are innately endowed for psychological development. Montessori believed that children having the liberty to choose and act freely in a proper school environment would develop better and faster. This method is widely used for infant-toddler, preschool and kindergarten, and elementary education; the extension to higher classes is somewhat mixed. It is a relatively expensive system that has a less structured curriculum. Since it does not encourage cramming large amounts of information and, instead, emphasizes creativity and independent thinking, it can more easily adjust to external changes.

Notable also are the Krishnamurti Foundation schools, established with the aim of bringing about a radical transformation in human consciousness. Following the philosophy of J. Krishnamurti, in addition to academic proficiency, these residential schools attempt to awaken intelligence and sensitivity in children in a non-competitive environment. Among them are the Rishi Valley School in Madanapalle (Andhra Pradesh), and the Rajghat Besant School in Varanasi; the medium of instruction in these schools is English. While they have succeeded in providing high-quality holistic education in the existing academic environment, they are expensive, and well beyond the means of the masses. And it is not clear how they will fare in the rapidly changing, technology-driven environment for mass education – especially, as they are affiliated to existing School Education Boards.

Home schooling, in which students are taught/educated at home and only appear in Board-level examinations as private students, has also been an option. It requires significant discipline and time commitments from parents. With substantial, high-quality 'courses' now available on YouTube, this task has been made much easier for parents. However, just as in the two paradigms discussed earlier, this method is not suited for the mass education of large hordes of students.

While the existing, highly-regulated school systems can handle very large numbers of students, as already mentioned several times, they are not sufficiently flexible to adjust to the fast-changing ideas spawned by the digital revolution and AI technologies, which make current curricula and supporting teaching materials obsolete faster than the systems can adjust to.

The Changing Face of Education. Until the 1960s, the output of high-school graduates was in 'balance' with the capacities of the universities for incoming students, in the sense that it was much easier to get admission to universities and departments of interest. This began to change in the 1970s, when the output of high-school students from the large increases in the number of schools throughout the country began to overwhelm the capacities of universities, which had not expanded to keep up with demand. Eventually, this resulted in large increases in the number of universities and autonomous institutions. And, for the first time, it made *private* universities, engineering and medical colleges – which had always been looked upon with suspicion as being money-making, elitist bodies unfair to the common man – acceptable: Their standards were to be regulated by bodies such as the University Grants Commission (UGC), the All India Council for Technical Education (AITCE), and the National Medical Commission (NMC) that were set up, respectively, in 1956, 1945, and 2020 (when NMC replaced the earlier Medical Council of India, MCI, established in 1933). So far, the regulation of such private universities/technical colleges/medical-colleges, by these regulatory bodies leaves much to be desired.

The role of English. Early on, the consensus among educationists was that the medium of instruction for primary education should be the regional language (mother tongue); English would be added as a second language at grade 5. A third language, such as Sanskrit, could also be taught. The medium of instruction in government schools for all the grades became the regional language. A small number of elite private schools – interestingly called Public Schools, modeled after such elite schools in the UK – with English as the medium of instruction, have existed for over 150 years.

With the use of regional languages for instruction, while the 'official' role of English initially declined, both for pedagogical and nationalistic regions, many parents – especially in large urban areas – wanted their children to be in English-medium schools to prepare them for universities and professional colleges, in which the medium of instruction continued to be English; and, because proficiency in English was preferred in the overall job market. Also, in addition to being the preferred worldwide language of communication for science and technology, the advent of computers, the internet, and smart phones have now made English a 'worldwide' language.

Awareness of the accelerating shift from a basically agriculture-based society with little need for education, to an industrial society requiring educated workers, to now a rapidly changing knowledge-based environment – which places a high premium on high-quality education – has increased the demand for English-medium schools, first in urban areas, and then even in the most remote rural regions. This demand has spawned a new 'industry' for English-medium private schools, most of which have very poor standards. In several states, government schools now teach English from Grade 1, and even use it as the medium of instruction. English, now an 'international' language that provides a competitive advantage, is here to stay. In recognition of the importance of education, many English-medium schools, some with bus services, are springing up, even in remote villages.

Evolution of School Systems. Besides government-run schools that educate the largest number of students, demand has fueled the growth of two types of English-medium schools: NGO-run nonprofit schools, and for-profit private schools.

A good example of an NGO-run nonprofit, large school system is that of the Dayanand Anglo Vedic (DAV) schools, originally founded in 1886, managed by the DAV College Managing Committee (DAVCMC) in New Delhi; it is likely the largest Indian education NGO. It has three types of schools: (1) Independent public schools, fully funded by student fees and managed by DAVCMC, (2) Grants-in-aid schools in which part of the running expenses are provided by State Governments, but run by DAVCMC, and (3) Project schools in which both the infrastructure and running expenses are provided by project authorities, such as by the National Thermal Power Corporation (NTPC); and Semi-project schools in which only the infrastructure is provided, such as by the National Hydro Power Corporation (NHPC) – but in both cases the schools are administered by DAVCMC. Besides urban areas, DAV schools have even been set up in remote rural areas, especially in North India. The medium of instruction in these schools depends on the Education Board to which the school is affiliated: normally English in CBSE and ICSE Boards, and regional languages in State Board schools.

DAV schools are known for student discipline, trained teachers, and rigorous academics, resulting in good results – the students do well in the Board examinations. But, like other schools preparing students for Board examinations, they are forced to subject their students to rote learning and cramming.

The increasing demand for better education is fast changing the role of private schools: The success of some urban English-medium schools has spawned very profitable franchises – like fast-food franchises – in which for a large initial consulting fee, and large recurring annual fees that depend on the number of students enrolled, an entrepreneur (franchisee) is helped in setting up the school, monitoring the quality of teachers being hired, and even training them. The entrepreneur is free to 'sell' his school (franchise) to others. One successful example of such a franchise is that of the Delhi Public School – which initially was set up in Delhi (Mathura Road). One advantage of this system is that it can be set up in remote areas, when there is a sufficient demand from parents. But its students undergo the same cramming and rote-learning routine that in India is considered education.

Evolution of the Coaching Industry. With admission to colleges and universities becoming very competitive, students routinely began to have 'private tuition', first one-on-one, and then in groups. This has morphed into a vast, very profitable 'coaching industry'. And then, with students wanting to get into the IITs, 'coaching classes' became a 'must' to prepare for the entrance examinations.

The success of such smaller, one-room coaching classes soon grew to college, and even institute-level 'institutes/colleges', many with residential facilities for the students. Admission to them is solicited by hoardings, which have pictures of successful students with their rankings, throughout the country.

Such coaching institutes are distorting the basic high-school system: In the 10+2 school system, a large body of aspirants spend the last two (+2) years full time in coaching institutes. This is made possible by connivance from schools that register these students and provide them with 'ghost' attendance.

Such is the state of our High-school system becoming: It is evolving to maximize the chances of students getting sufficiently high marks in competitive examinations by continuously cramming information and taking practice examinations. Borrowing from mass manufacturing in industry, our education system is becoming a mass-production process for generating large numbers of burned-out 'worker bees', who after admission to colleges/institutes can relax, and only worry about expected pay packages.

Changes in Employment Options. The move from a basically agricultural society to an industrial society in the 20th century first led to engineering being the preferred vocation, with the 'best' students good in mathematics competing to get into the small number of engineering colleges. For those not mathematically inclined medicine was the preferred second choice – law was the last choice. Others, with degrees in the arts and social sciences, mainly preferred jobs in the various Indian Administrative Services – such as IFS, IAS, IPS, and IRS, that are recruited through a three-step examination conducted by the Union Public Service Commission (UPSC).

To set up benchmarks for high academic standards, the first five IITs (1950-1961) and the All India Institute of Medical Sciences Delhi (AIIMS) (1956) were set up as *autonomous* institutions of national importance by acts of parliament. Now with worldwide reputations, these institutes successfully provided national models for curricular reform in universities. Originally two Indian Institutes of Management (IIMs) were set up in Kolkata and Ahmedabad – which in 2017 were also deemed as institutions of national importance by acts of parliament. Later, in rapid succession, the IITs, AIIMS, and IIMs were expanded, respectively, to 23, 24, and 21. With the lack of high-quality faculty, this rapid expansion has significantly reduced the overall quality of these institutions. Based on these models, a large number similar, high-quality law schools/universities have also been established.

With these additional opportunities, the coaching industry has expanded to cover admissions to colleges and competitive examinations – such as the civil services examinations conducted by the UPSC – to all disciplines.

Government Policy. On 29 July 2020, the Indian government approved a new, ambitious National Education Policy aimed at introducing several changes to the existing Indian education system: Make pre-primary education universal and emphasize achieving foundational literacy/numeracy in primary school and beyond for all by 2025. It recommends reducing curriculum content, and enhancing essential learning, critical thinking, and promoting more holistic, experiential, discussion- and analysis-based learning. Also recommended is a revision of the curriculum and pedagogical structure from a 10+2 to a 5+3+3+4 system to optimize learning based on cognitive development of children. This *massive* reform effort will affect some 265 million students being taught by about 9.5 million teachers in about 150,000 schools. As difficult as this task is – it's already 2025! – this reform effort does not account for the exponential changes driven by the fast-changing, instant-communication, artificial-intelligence, and digitally-driven environment.

THE HUMAN DIMENSION

We humans are not machines: Although the very complex mechanisms of our thought processes are still not well understood, besides our ability to analyze diverse data types received through our five main sensory organs – eyes for sight, ears for hearing, skin for touch, tongue for taste, and the nose for smell – it is our emotional being that clearly separates us from machines. Our moods can change – from feeling happy to being depressed. We can smile, laugh, cry, and get angry. Music and dance can affect our emotions, as can the fine arts. And our psychological makeup is important for our ability to learn.

Our mental abilities are known to change with age – it takes us about two years to control our bowels, and about 5-7 years to learn and master our most difficult accomplishment, the ability to learn and communicate via language, be it by speech or sign language. And, in the early years, till about age 18, the cognitive functions of the brain continue to grow; in the early years the brains of girls mature faster than of boys. During this critical period, while the cognitive skills improve considerably, the mind is subject to many psychological pressures – several now caused by the 'instantaneous' unfiltered flow of information from addictive posts on social media. It has now been established that the significant time spent by youngsters on digital social media and games hinders the growth of the brain cognitive processes, and affects their psychological balance and moods.

It is during these critical brain-development years that the bulk of formal education is imparted. Over the years, psychologists have mapped the cognitive growth of the brain, and the ability to learn with age. Such studies have provided inputs for the design of age-related curricula. But now, with the very rapid changes being caused by universal, instantaneous communication provided by the internet and social media, and the impact of rapidly emerging Artificial Intelligence platforms, we need to better understand how these changes will affect our ability to learn, and to adjust to such changes.

The impact of future, very-rapidly changing technologies on humankind has many dimensions: First, what is the ultimate capacity of humans to adjust to continual external changes? Second, just as traumatic events, such as witnessing cranage in wars, can induce mental health conditions, such as PTSD (Post-Traumatic Stress Disorder) in which the entire cognition and mood of an individual is adversely affected – with continuing negative emotions such as fear, anger guilt, and shame – can exposure to rapid changes beyond the innate capacities of humans to cope with change cause similar mental disorders? And third, what will it take to understand such underlying issues, and to then develop radically different school systems to cope with these changes?

Growth of Human Population. From the times of the Pharaohs the lot of humans have improved enormously: For the longest time, life expectancy was very low. While it has not changed much in the past; from about 1700 till 1900 it was on the order of 30 years. Then, because of lower infant mortality, better nutrition, and advances in healthcare, life expectancy has increased linearly from about 30 years in1900 to about 75 years now.

World population hit 1 billion in 1804. Then, after intervals of 123, 33, 14, 13, 12, 12, and 11 years, it rapidly increased to 2, 3, 4, 5, 6, 7, and 8 billion, respectively, in 1929, 1960, 1974, 1987, 1999, 2011, and 2022.

Since independence, India's population has grown about four-fold to about 1.4 billion from about 340 million in 1947. During this period, the number of schools, universities, and students have grown from about 400, 19, and 5,000, respectively, to about 1.5 million, 751 (plus 35,000 colleges), and 265 million (plus 43 million in higher education).

Catering to the needs of this enormous number of students has required an unprecedented increase in the educational infrastructure: construction of large numbers of schools, colleges, and universities; and training very large number of teachers. While much progress has been made, the logistics of carrying out this daunting task in this short time, especially with inadequate funding, has affected the overall quality of our education enterprise.

Concluding Remarks

Very rapid changes in technology, capped by the AI Revolution, pose an existential threat to the relevance and viability of our current school systems. And the governing bodies that oversee the planning and implementations of the high-school curricula and evaluation systems, are mired in fruitless debates about marginal modifications of current curricula. They neither have the vision nor the 'bandwidth' for the 'out-of-the box' thinking required to make the necessary, truly radical changes to address this existential threat: What should the structure of the schools of the future be? What role should YouTube-based distance learning via the internet have? Should such 'studying' be personal, as in home schooling – each student directly connecting from home to a remote YouTube server – or should such YouTube-based material be accessed by a small number of students supervised by a mentor (teacher) in a common classroom, thereby providing social interactions to better prepare them for society? What about team activity, such as sports, which are known to inculcate a sense of 'we or us' as opposed to 'me'. How should the progress of students be assessed or graded?

Clearly, tackling this daunting task will require new, greenfield incubators (experimental schools) – staffed by younger, highly-motivated passionate individuals trained in diverse fields, among others, such as neurology, psychology, sociology, human development, history, music, the fine arts, mathematics, physics, chemistry, and biology – that have total freedom and adequate funding to imagine and implement education systems of the future. And, having dozens of such independent incubators, which hopefully will explore different paths, will provide viable models for future schools for mass education.

Having multiple models (incubators) is critical: When the first five IITs were created by an act of parliament, because most faculty and directors were cannibalized from existing technical colleges, the initial curricula of the IITs were relatively uniform and only marginally better than in existing engineering colleges. Although they had absolute autonomy to implement new curricula and examination systems, the 'straitjacket' on their thought processes from their education and teaching experience prevented them from using this autonomy. This was not helped by the directors chosen by the Ministry of Education – in one IIT the first Director was an Army Brigadier, in a second IIT the first Director was a retired Chief Engineer of PWD from Punjab! Of the five, it was IIT Kanpur that made radical changes by introducing the semester system, course-wise promotion – with summer make-up courses; many common core courses for all disciplines; emphasis on engineering sciences; one required high-quality humanities and social sciences course per semester – later fine arts and music were added to the curriculum; summer industry placement for students; and final job placement in industry. It was the first institution to teach digital computer technology to all students – it was the first to award a degree in computer science, and to form the first computer science department in the country. It required faculty to submit grades within 72 hours of an examination; the Institute-wide results were declared within 72 hours of the last examination. And, it was the first educational institution to give autonomy to its student body, which was led by an elected student Gymkhana President; this body initiated the first pan-national cultural festivals that later became popular throughout the country. Much of this success resulted from three early very non-traditional policy decisions: (1) In hiring faculty, it emphasized qualifications (PhDs) with experience having almost no weightage. And it *proactively* went out to look for, and to entice outstanding candidates from all over the world. (2) All academic decisions were made by faculty committees with representatives from all departments. Membership was by rotation and involved younger faculty. And (3), to deemphasize bureaucratic constraints, the heads of department were appointed by rotation for three-year terms. This inculcated a sense of ownership that radically changed how science and engineering were taught.

The task of developing models for high schools of the future is more daunting than the creation of the IITs to overhaul technical education. For this experiment to succeed, true autonomy from government interference, adequate funding, AND scouring the world to attract highly-educated and *passionate* persons as teachers will be critical to the success of this enterprise.