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# Editorial

# Curiosity: Mother of Innovation in Biotechnology

**Looking back**

Curiosity drives learning, beginning in childhood. An educator's objective is served when students are learning to learn, questioning the world, imagining, and creating solutions. The major part of my own biochemical engineering education started with curiosity about phenomena and systems: physical, chemical and biological. Luckily, for the last 50 years, a combined chemical engineering and biology education program on the IIT Delhi campus has trained hundreds of engineers, technologists and educators making a global impact. This paper is an attempt to reflect on various disciplines which enable ingredients of successes. Swami Vivekanand, great monk-philosopher of India who enlightened the world in the last part of 19$^{th}$ century, once wrote, "have strong faith in yourself, your body and mind; fill the brain with high thoughts…. place them day and night before you, let brain, muscles, nerves, every part of your body be full of that idea….and out of that will come great work." By connecting literature, education, and experience, we form ideas and hypotheses. Through dedicated collaborations among institutions and industries, we drive continuous improvement of both education and acceleration of innovation processes. It is vital that faculty foster curiosity in their students. If 'necessity is the mother of invention', then curiosity too gives birth to innovation. Every teacher has the quest: I'm teaching, are my students assimilating, gaining knowledge, solving problems, and most importantly teaching someone what they have learned already? Whether it's practicing one's profession or religion, learning never stops. Looking back is easy but envisioning the future can be challenging - like joining pieces of a jig-saw puzzle, especially without a picture of the solution in front of us!

**Human connections**

Steve Jobs has said: future dots will connect when you connect with others. Human progress, described by Yuval Noah Harari in his widely acclaimed book: 'Sapiens-A Brief History of Humankind', is also packed with dots of knowledge and connections of our 'Hunting-Gathering' past (Harari, 2014). The famous author has written on our progress, after extensive research on trends and their causes, to predict future innovation. Our ancestors learned to use fire for cooking and culture was initiated. New culture gave birth to 'Agri-Culture' about twelve thousand years ago, and humans decided to settle down, form communities, and breed different "cultures." Communities learned to domesticate plants for more food supply, leading to leisure, diverse health conditions, social and class division. Communication methods were developed. Evolutionary knowledge led to Scientific Revolution about 500 years ago, replacing old answers with new questions, admitting ignorance to develop new knowledge. The modern world invented energy interconversion, leading to the Industrial Revolution which generated new materials, energy sources, amassed big data and populated massive computing. Moving fast forward, we are now into the realm of "Biological Engineering", for sustaining our future, making natural choices and creating "intelligent" designs, to restore the Earth.

**Trends in Technology**

S-shape curves typically describe trends of new products and technologies, e.g., first phase (incubation) gives birth to an idea, next phase (growth) goes through exponential development, multiplying uses, and then product/technology matures and diminishes, or gives rise to better ideas. Such trends and life cycles, teach us how innovation unfolds, takes shape, and sometimes prepare us to anticipate the next 'find'. The development of Logic circuits is a case in point, now with speeds supporting complex models for AI. The exponential increase in speed and intensity of information generation and processing benefitted the field of "Bio-Logics", fueling curiosity and innovation in the field of biotechnology. Interestingly, biologic systems also use potentials (chemical and electrical), fluxes (flow of photons, electrons, protons, ions) through protein arrays (circuits) for response and control under environmental stimulus. Obviously, silicon processors and biology developed along different timelines. Living systems developed over millions of years through natural selection, but biology is more than digital (binary); has continuous spectrum (interaction, mutation, growth, maintenance, infection, co-existence, inter-dependence, death). Most biological systems work continuously (like a clock) and cycle through generations (self-replicating, self-energizing, adapting, symbiotic, parasitic), attaining different states (dormant, vegetative, active, lysis, infectious) (Losick, 2014).

About 50 years ago, biotechnology caught investors' interest, after the advent of recombinant DNA technology. New biotechnology companies were started to engineer DNA for designing and producing bioactives (enzymes, proteins, peptides, antibodies, antigens, growth factors). Companies like Genentech, Amgen, Biogen, Cetus, Genencor, Novozymes paired with established companies like Roche, Johnson & Johnson, Eli Lilly, Novo-Nordisk, Kodak, Monsanto, Procter & Gamble, DuPont and others, to deliver biotech solutions in all areas of medicine, agriculture and household applications. As mentioned before, computer- and bio-technologies advanced almost simultaneously for logical reasons. Biotechnology continues to expand hosts of solutions for health and nutrition of humans, animals and plants. Engineering and science disciplines in colleges, universities and industries have re-assembled to teach design-build-operate *cell factories* to produce engineered proteins and microorganisms.

Industrial biotech companies produce not only bioactives but also biomaterials and biofuels (Arbige, et al 2019). Better, cheaper, faster tools have synergized advancement of biotechnology in industrial, health and agriculture sectors. Micro-organisms, designed and built by recombinant DNA (rDNA) technology and gene editing, can efficiently convert renewable carbon feedstocks in fermenters, for commodity scale applications. Fast pace, large scale, low cost manufacturing applies reactor engineering (mass, heat, and momentum transfer) principles to microbial cell factories for producing enzymes, health and nutrition proteins, biofertilizers, biomaterials and bioenergy. One of the fastest growing areas is nutrition and health of the gastrointestinal tract. The gut is the largest immune organ, where microorganisms promote activation of immune-competent cells. Not surprising, like fermentor processes, trillions of gut bacteria also metabolize foods, control pathogens, respond to health changes in the body and defend us against invading pathogens and viruses. For example, Griffithsin (GRFT), a lectin protein present in red algae *Griffithsia*, has antiviral activity at very low (pico-molar) concentrations, blocking viruses from infecting the host. GRFT also prevents cell fusion between infected and uninfected host cells, inhibiting the spread of virus in the human body, such as COVID-19. Microbial or plant cell factories, could be used to produce pure GRFT protein very quickly and economically for human antiviral therapy (Decker, et al 2020).

**Moving forward**

Modern education must foster continuous learning for a sound career. Mastery of a field starts with curiosity, asking questions, visualizing progress, generating perspectives, connecting with others, defining better problems, exploring best solutions, trying new roles, navigating changes and teaching others. A degree is not a guarantee that deep learning has been experienced. The words of the famous Bollywood lyricist Majhrooh Sultanpuri are so inspiring: "*main akela hi chala tha janib-e-manzil magar, log saath aate gaye aur karwaan banta gaya"* meaning "I started all alone towards the goal (but) people kept joining to turn into a caravan." The Potential (voltage) of newborns is nearly the same, Learning (current) can overcome Ignorance (resistance). GURU is the Transformer of knowledge, from 'gu' (darkness) to 'ru' (light**),** a guru (teacher) must spark curiosity to know more and innovate. One should not be afraid of seeking mentors, getting feedback, stepping outside of comfort zones, because it's all for expanding horizons. From parents to teachers, colleagues to company leaders, my "gurus", inspired and instilled love for working in new areas of biosciences, applying chemical engineering skills to biotechnology, and most importantly problem solving. My education in India, particularly biochemical engineering training, somewhere sometime, must have injected into the vision, to work on industrial biotechnology, well before its global acceptance.