Biology without borders

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The borders between science disciplines are becoming increasingly blurred. In particular, biology is synergizing strongly with other disciplines, and creating new ones, ranging from molecular biology and biophysics to computer-aided drug design, computational biology and biomedical engineering. Synthetic biology is a field conceptualized by engineers, who wanted to design, edit and synthesize living cells like building machines – the only difference is that the components are biological. These developments are supported by the availability of supercomputers and high-speed research and education networks like the Indian National Knowledge Network. Also, the expected timeline to translate basic research into a viable product is dramatically reducing, as exemplified by the recent COVID-19 experience.

Most of the exciting problems in science and technology today are multidisciplinary. Design of nuclear power plants, space launch vehicles or advanced fighter aircraft in mission–oriented agencies are a few examples of multidisciplinary technology projects. The borders between science disciplines are also continuously becoming blur. For example, density functional theory (DFT) is popular for first principle energy calculations and is routinely used in condensed matter physics nowadays. DFT is equally popular for calculations in quantum chemistry. The border between theoretical chemistry and theoretical condensed matter physics is nearly absent. And very often, both handle biological problems.

Traditionally, the natural sciences have been divided into two branches: physical sciences and biological sciences. We now also have, for example, 'biological physics', which is the study of biological systems as physical systems. Biological crystallography is a good example. Venkatraman Ramakrishnan and two others were awarded the 2009 Nobel Prize in Chemistry for solving the structure of the ribosome, which is the most complex structure solved so far using X-ray crystallography. The problem is in biology, the techniques used are physical, and the Nobel Prize was awarded in Chemistry. In chemical reactions, catalysts play an important role. Similarly, biocatalysts are used for the production of pharmaceuticals, vitamins or nutraceuticals and other biochemicals.

Computer-aided drug design

Drug design is a key aspect of biology, and the recent COVID-19 pandemic has brought it to the forefront. Computer-aided drug design has led to the development of novel drugs in a cost-efficient manner in the past few years. Several computational approaches such as molecular dynamics studies, ligand docking for identifying druggable targets and identification of structure–function relationships have been utilized in various phases of the drug discovery cycle. Artificial intelligence/machine learning is also becoming useful in identifying good drug targets.

Biomolecular and cellular-level problems

The problems at this level are, for example, targeted therapeutics, e.g. the science of delivering drugs to the appropriate area in the body (like in cancer). All this needs skill to work at the life sciences/physical sciences interface. Radiopharmaceuticals can be used for studying the functioning of different organs of the body, such as heart, brain, lungs, and for the detection of tumours, identifying hormones, etc. Radiation from radioisotopes can also be used for the treatment of cancer by tele-therapy and brachy-therapy.

Biology, mathematics and electronics

Biomathematics is the use of mathematical models to help understand phenomena in many areas of biology. Computational biology, which includes bioinformatics, is the science of using biological data to develop algorithms or models in order to understand biological systems and relationships. This field was nucleated by the advent of DNA sequencing, and is supported by the availability of supercomputers and high-speed networks like the Indian National Knowledge Network (NKN), a research and education network which now interconnects more than 1600 knowledge institutions in the country. One can form 'grids' in NKN, where specialists in a field can get together selectively to exchange ideas and collaborate. One of the earliest grids was on 'brain imaging', which brought together experts in Alzheimer's, stroke, etc.

Biomedical engineering

Biomedical engineering is the application of the principles and problem-solving techniques of engineering to biology and medicine. There are many academic institutions active in this area. For example, the Centre for Biomedical Engineering was established in 1971 at the Indian Institute of Technology Delhi, as a joint venture with the All-India Institute of Medical Sciences, New Delhi.

The Indian medical devices market is expected to grow to about US$ 50 billion by 2025. Today 70–80% of the demand is met by imports. In view of this, the Government's new policy encourages both FDI and indigenous manufacturing. Medical device design is clearly interdisciplinary – the need is biological and the device is based on physical sciences. Today, there are good research groups, both in national laboratories and the university system.

Other important interdisciplinary fields in biology

Biochemistry is a classic example, where biology is broken down in terms of chemical reactions. This has become a fundamental discipline, where metabolism of biological molecules, be it small or macromolecules, has remained the dominant part. In terms of the evolution of newer disciplines in biology, knowledge of biochemistry has become vital. Another case in hand to discuss is biophysics. A simple definition of physics as such is that it deals with matter, energy and their interactions. The dimensions range from particle physics to astrophysics. Knowledge of the structure of matter is fundamental to physics, and biophysics has evolved to study the structure and interaction of biological molecules through the development of incisive technologies such as X-ray crystallography, mass spectral analysis and cryo-electron microscopy, to name a few.

Molecular biology is another striking example which has developed its own vocabulary. It has grown from the edges of physics, chemistry, biology, computational biology and genetics. At the end of World War II, there was an exodus of physicists who were unhappy with the carnage and death in the war, and sought new pastures in biology, an uncharted terrain. Max Delbrück, a physicist by training, who was influenced by Erwin Schrödinger's book *What is Life*? (1944) as well as by the physicist Niels Bohr, shared the Nobel Prize in Physiology or Medicine for his work on bacteriophages. Fundamental studies on DNA replication and mutation became the bedrock for the growth of molecular biology.

There is a long line of physicists who made outstanding contributions to this field, including G. N. Ramachandran (GNR) and V. Ramakrishnan. The former laid the foundation for studies on protein conformation, while the latter analysed complex biological structures such as ribosomes. Linus Pauling, a chemist, applied quantum mechanics to understand the nature of the chemical bond and elucidated the structure of the alpha helix, an important structural feature of proteins. GNR was a step ahead with bond-angle measurement and energetically permitted bond angle of the peptide (ϕ) against the amino acid (ψ), a consequence of his elucidation of the triple helical structure of collagen, which Pauling acknowledged: 'GNR's team had pipped his group to the post in the race for the collagen structure.'

Har Gobind Khorana was an organic chemist who was the first to chemically synthesize a nucleotide. Following on the trail of Watson and Crick, who laid the foundation for establishing the central dogma in molecular biology (DNA–RNA–protein), with their basic unravelling of the DNA structure, Khorana competed with Marshall Nirenberg and others in elucidating codon assignments. In the 1960s, we recall the thrill of looking for breakthrough information from papers describing the various steps in transcription and translation. Although the term 'molecular biology' has remained to indicate a field of investigation, it is not a single discipline. With the deciphering of the human genome sequence, scores of genome sequences from all life forms have been made available. This has given birth to 'omics' sciences, where the approach is not to just look at single genes or proteins or metabolites. It has become possible to consider multiple genes/proteins/metabolites involved in metabolic pathways underlying biological phenomena. Bioinformatics/computational biology has become integral in analysing large volumes of chemical data.

Biochemistry/molecular biology was reductionist to start with. This was necessary to interpret mechanisms at the molecular level. Over a period of time, it has been recognized that integration of all data, chemical and biological, has to take place to interpret biological phenomena. Simultaneously, integration of all the sciences has given rise to the field of systems biology. This has also happened out of necessity to understand complex diseases like infectious diseases, diabetes and cancer.

While there is no limit to knowledge exploration by the human mind, the next evolution in biology transcends all sciences. Synthetic biology has evolved beyond imagination and has outstripped semiconductor physics and micro-electronics. Interestingly, the whole field is conceptualized by engineers, who wanted to design, edit and synthesize living cells like building machines that run on valves, wires, transistors, etc. The only difference is that the components are biological, be it genes, RNA, transcription factors, etc. The goal is to create a replicating organism with designed codes that can make any new molecule, generate energy at a low cost, reboot computing using DNA, make new devices, etc. Led by Tom Knight at MIT, USA, teams of engineers and scientists have made incredible progress and the components are available for research globally. Student teams now participate in International Genetically Engineered Machine (iGEM) competition.

Concluding remarks

Cybernetics deals with communication and control systems in living organisms, machines and organizations. The outcomes of these actions are taken as inputs for further action. Cybernetics is a precursor to fields such as artificial intelligence and cognitive science, and has also evolved into the field of artificial neural networks.

An artificial neural network is like a massively parallel, distributed processor made up of simple processing units (artificial neurons). It resembles the brain in two respects: knowledge is acquired by the network from its environment through a learning process; synaptic connection among the artificial neurons is used to store the acquired knowledge. Now, cognitive science is beginning to benefit from artificial intelligence, both as a model for developing and testing ideas about how the brain performs computations, and as a tool for processing the complex datasets.

We do hope that the New Educational Policy would provide future generations with options to do science without borders. India still has a long way to catch up with the developed world, although our ancestors from the Vedic period were then on top of the world. We lost our way as well as our moorings.

While interdisciplinary science has almost led scientists to achieve great heights, the global community has recently taken a hit. A tiny virus like the SARS-CoV-2 causing the COVID-19 pandemic could destroy life, leave us struggling to find more clues to its trajectory, and potentially challenge all the sciences. Nature still has secrets that keep us on the edge, and teach us humility.

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