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GUEST EDITORIAL

On interdisciplinarity

'Interdisciplinary' is a buzzword today. What is its significance, which areas are interdisciplinary, and how the practice in India is, are issues that need analysis and introspection (Balaram, P., *Curr. Sci.*, 2012, **102**, 1345–1346). I offer my limited views as an illustrative summary of the underlying challenges. I feel the two areas of sciences on which interdisciplinarity rests are chemistry and physics. Mathematics is not included here, being outside the realm of experimentation, though it is an essential tool for interdisciplinary research.

To amplify, consider biology which is usually divided into botany, zoology and physiology. Apart from the important observational areas of taxonomy, behavioural biology,..., modern topics hinge on chemistry and physics. Biochemistry and molecular, structural and computational biology are cases in point. On this, two themes are crucial for life: (1) photosynthesis and (2) electron transfer. In (1), sunlight comprising photons is absorbed by chlorophyll and energy is stored in carbohydrates such as sugar. In (2), electron transfer reactions occur in haemoglobin which is an iron-rich protein found in the red blood cells of most vertebrates. Interestingly, while (1) and (2) are relegated to botany and physiology/zoology, both are governed by quantum laws.

The other contextually relevant subjects are agricultural, earth, engineering, environmental and materials sciences. We expand on this classification below, but before that it is pertinent to dissect the two stated topics of basic sciences, and point out a fundamental difference. The four distinct pillars on which physics is snugly ensconced are classical mechanics, electromagnetism, quantum mechanics and statistical mechanics (subsuming thermodynamics). Everything else such as nuclear physics, solid and liquid state physics, quantum field theory leading to particle physics, cosmology, etc. sprout from these four pillars. When it comes to chemistry however we are not in such a clear-cut situation. Though the quantum mechanics of bonding, reactions and spectroscopy is evidently the binding theme, chemistry is partitioned into inorganic, organic and physical chemistry. Why, I have often wondered? Imagine the absurdity of having individual departments of classical and quantum mechanics.

We now expound the nature of interdisciplinarity mentioned earlier. Take the post-earthquake situation. The resultant shock waves can cause liquefaction, sand piling and outpouring of over-pressured mud. Hence, the soil is irretrievably altered, which in turn affects yield. Such studies are truly interdisciplinary – they straddle physics, chemistry and geology. Another area is the already-mentioned chemical reactions, which are at the heart of not just chemistry and biology, but also ionization in stellar astrophysics. However, reaction theory is anchored on chemical equilibrium and rates of activation over free energy barriers in a landscape of reaction coordinates. Among those who made seminal contributions, H. Eyring and M. Polanyi (1931), E. Wigner (1932) and H. A. Kramers (1940), came from various disciplines. Consider also the amazing example of the carbon allotrope: graphene. Though it has novel material properties all the attributes can be ascribed to quantum mechanics. Finally, we cite the contemporary topic of biological engines that are responsible for transport in living matter on nanoscales (Dattagupta, S., *Curr. Sci.*, 2018, **114**(6), 1149–1150), an understanding of which requires thermodynamics.

Perhaps the theme that made the strongest interdisciplinary impact is diffusion as can be judged by the citations of Albert Einstein's (1905) paper. Although Einstein's original thesis dealt with the rheological properties of particle suspensions and a theory for the botanist Robert Brown's (1826) observation of random-motion of pollens in water, the work had an extraordinary range of applications to numerous interdisciplinary areas: (i) Construction industry, based on what has now emerged as the subject of granular matter; (ii) dairy industry, through the colloidal suspension of casein micelles in cow's milk; (iii) ecology, involving the random movement of aerosol particles in clouds; (iv) geophysical exploration of diffusion of oil through porous rocks and even (v) stock market fluctuations.

Moreover, Einstein's work spurred the development of stochastic calculus, related specially to Markov processes and dynamical semi-groups.

At this stage it is interesting to stress that many techniques – microscopy, X-ray diffraction, laser spectroscopy, magnetic resonance, Mössbauer effect, neutron scattering and synchrotron radiation – all emanated from physics laboratories, but find their use in most interdisciplinary areas discussed here.

Before leaving this brief discourse it is interesting to note that although number theory belongs to 'pure' mathematics, it has found applications in computer science and cryptography. Similarly, statistics is being profitably applied to psephology. Therefore, the subdivision of mathematics into ‘pure’ and ‘applied’ is not conducive to interdisciplinary research.

One subject that cries for a multi-pronged approach is environmental sciences in view of the heightened concern on climate changes. Clearly, a concerted effort of biologists, chemists, geologists, physicists and model-builders is urgently needed to tackle this enormously challenging threat.

Having extolled the virtue and necessity of interdisciplinary studies we ask the question: Are we sufficiently interdisciplinary in our approach to research and teaching? The answer, unfortunately, is ‘no’.

First consider the practice of teaching. It is deplorable that the fundamental topics of quantum theory and thermodynamics are taught *separately* in physics and chemistry departments. In the case of quantum mechanics, physics teachers appear obsessed with representation theory and axiomatic operator algebra; chemistry teaching, on the other hand, lays more stress on pictorial analysis of wave functions, orbitals, etc. A physics student may be more conversant with creation, annihilation, number operators and Hermite polynomials in the context of harmonic oscillators, but is sadly oblivious to what the corresponding wave functions look like. Similar is the situation in H and H-like atoms – while physics teaching concentrates on Laguerre polynomial solution of the underlying Schrödinger equation, very little time is usually spent on the nature of the wave functions, which is crucial for a proper understanding of bonding and formation of solids. One other instance comes to mind – whereas physicists labour on angular momentum, scattering theory,.., the chemists expound on semi-classical W. K. B. approximations, etc. The point is all these topics are equally important; if only the two communities joined hands, there would be possibilities of creative collaborative research, such as witnessed in the resonating valence-bond approach that led to the most imaginative theory of high-temperature superconductors.

We have already lamented the demarcation of chemistry into departments, in our context. In this regard, I recall a contrasting and eye-opening American experience. Many stalwarts who had made significant contributions to my own specialization of statistical mechanics (a topic normally thought to be within the domain of physicists) – B. Berne, D. Chandler, M. Fisher, R. Gordon, L. Onsager, H. Shuler, B. Widom, P. Wolynes, R. Zwanzig, to name a few – all belonged to chemistry departments. The teaching of earth sciences, in itself an interdisciplinary area, is even more fragmented – into geochemistry, geophysics, mineralogy, seismology and so on.

A moment’s reflection reveals the malaise is in the school system itself. Biology – a hugely important area – is kept outside the high school syllabus of chemistry, physics and mathematics majors. Conversely, biology majors are not required to study mathematics. Is it a surprise then that we do not produce a Francis Crick – a physicist who was instrumental in unravelling the DNA structure, or Walter Kohn – another theoretical physicist who received the Nobel Prize in Chemistry for his contribution to the density functional theory of many-electron systems? Indeed there have been other instances of physicists winning the Prize in Physiology or Medicine or biologists in Chemistry, and vice versa. A closer-to-home example is V. Ramakrishnan who was trained as a physicist, worked on a biology problem and went on to win the Nobel Prize in Chemistry.

The dearth of interdisciplinary research arises from abysmal interest in collaborative work. Not only do we not see much evidence of cross-disciplinary partnerships, theorists do not seem to publish much with their experimentalist counterparts. In this aspect we are way behind Western scientists.

Why is there so much apathy toward interdisciplinarity, or are there deeper reasons? Well, it goes without saying that one has to be first and foremost grounded in one’s own discipline before embarking on interdisciplinary research. We seem unwilling to leave the comfort zones of our cocooned shell. The malaise germinates in schools themselves, wherein students are made to go to outside coaching centres for specialized training.

Interdisciplinarity presupposes out-of-the-box thinking. For this, one needs to have an unshackled mind which in turn requires unbridled time and space. But, where is the ‘time’? Our scientists are made to constantly strive to improve their API scores, impact factors and *h*-indices of their publications, in order to prove their mettle in selection committees for promotions, prizes and Academy fellowships; quantity appears to outweigh quality. Contrast this with the situation at the turn of the last century. J. C. Bose transited from microwave propagation to stress responses in plants; C. V. Raman, from Raman spectroscopy to the science of musical instruments and colour of flowers, and M. N. Saha, not only delved into the earlier-stated ionization theory, but also nuclear accelerators and river-distribution systems. Can we not derive inspiration from these glorious examples?

In conclusion, I feel biology must be brought back within the package of science teaching in schools. Imaginative courses on environmental and materials sciences could be designed in our teaching curricula. We surely need thoughtful teachers who can explain ‘advanced’ concepts in understandable terms and design textbooks with diverse and illustrative examples. Institutions also ought to be flexible in hiring faculty and supporting evolving inclinations of students. This would go a long way in not only encouraging students to get interested in science, but also in developing in them an overall perspective.

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