Dimensions of earth education

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Earth sciences comprises basic and applied components. Basic components include geology, geophysics, geochemistry, soil science, hydrology, climatology, oceanography and planetology. Applied components include topographic surveying, meteorology, civil engineering, petroleum engineering mining engineering, ocean engineering, and agricultural engineering. Additionally, there are trans-disciplinary fields such as biogeochemistry, ecological sciences and environmental sciences. Connections between earth sciences and society are central to geography, which integrates the earth's physical attributes with human behaviour.

Facets of earth education relevant to contemporary India are discussed with the hope that the perspectives presented will be of value to those in the academia, industry and the government, who grapple with the difficult task of adapting India's educational infrastructure to serve the country's emerging imperatives: sustainable ecology and food, water and energy security.

James Hutton founded modern geology during the 1780s, at the same time when the Industrial Revolution began. The rise of the earth sciences immediately thereafter was spectacular. During the 18th and 19th centuries, natural philosophers such as Lavoisier, Laplace, Fourier, Kelvin, von Humboldt and others pioneered the application of mechanics, thermodynamics and chemistry to understand the functioning of the atmosphere, the oceans and the lithosphere. Following Hutton's methodology, field geologists assembled stratigraphic successions inscribed in the rock formations around the world, and deciphered their equivalence in time, dating back to billions of years. By the turn of the 20th century, the major components of the earth's internal structure, its tectonic framework, patterns of circulation of oceanic currents and global climatic patterns had been established.

Modern earth sciences came to India early, contemporaneously with developments in Europe. The first astronomical observations were made in the erstwhile Madras Observatory in 1787. The Survey of India was established in 1767. In 1854, sophisticated triangulation surveys close to the Himalayas led to the hypothesis of isostatic equilibrium, suggesting that at some depth below the earth's lithosphere, all segments of the earth's crust exerted equal pressure. In 1856, the elevation of Peak XV (later named Mt. Everest in 1865) was measured at 8839.8 m, close to the present-day measurement of 8848 m. The first tidal gauge in the northern Indian Ocean was established by the Survey of India at Apollo Bundar, Mumbai in 1878. It now has the distinction of being only one of four tidal gauges in the tropics with records extending over a century. The first geomagnetic station established at Colaba, Bombay in 1841, and that established at nearby Alibag in 1906, together have the distinction of having gathered data continuously even during the war years. The Geological Survey of India was established in 1851. The discovery of striated boulders of glacial origin in eastern India in 1856, provided some of the earliest evidence for continental drift and plate tectonics. The India Meteorological Department was established in 1875. However, rainfall measurements began to be recorded much earlier. Thus, Chennai, Mumbai and Kolkata have continuous precipitation records for over 160 years. The earliest geology courses were taught at the Presidency College, Kolkata in 1892.

The first half of the 20th century witnessed the maturing of many specialized fields in earth sciences and engineering. As examples, one may cite historical geology, palaeontology, mineralogy, structural geology, marine geology, climatology, soil physics, soil mechanics and petroleum engineering. The physico-chemical processes as well as the mathematical equations fundamental to each of the specialities had been identified and enumerated. Focusing attention on specific components of the earth system, these specializations developed in isolation, with limited mutual interaction. Scientific understanding in various fields enabled vigorous development of natural resources such as fossil fuels, metallic and non-metallic minerals and construction materials. Impressive achievements were made in harnessing rivers, pumping water from great depths, transporting water over long distances, producing hydroelectric power and making deserts bloom. It seemed as though unlimited prosperity could be achieved through technological conquest of the earth.

Contrary to such expectation, evidence from around the world during the second half of the 20th century indicated that technology cannot conquer the earth at will, and that the price of aggressive intervention with earth processes is endangerment of the human habitat and destruction of ecosystems. It became clear that the earth is a finite body in which all living things have evolved to sustain themselves within finite budgets of solar energy, water and life-sustaining nutrients. In the finite earth, the lithosphere, the hydrosphere, the atmosphere and the biosphere are interconnected on many spatial and temporal scales. Gradually, sustainable resource utilization supplanted the old paradigm of conquering the earth. Dramatically, specialized disciplines that had hitherto developed in isolation began recognizing the imperative for mutual integration.

Aside from the damages caused by human activities, two palaeoclimatic findings have caught the earth sciences community by surprise. The first is that the west coasts of the Americas have experienced century-long mega-droughts between AD 900 and 1400. The second is that climate can change drastically from very wet to very dry conditions on a continental scale over a period of a few decades. Additionally, there is unequivocal evidence indicating that the earth's climate is noticeably warming due to atmospheric accumulation of greenhouses gases.

At the turn of the 21st century, emergence of environmental concerns, need for sustainable resource development, desire for equitable distribution of natural resources among all segments of the society, awareness of the possibility of prolonged droughts and global warming are having a pronounced impact on earth education structure in schools, colleges and research institutions. As educational institutions strive to adapt to emerging needs through modification of curricula and teaching methodologies, vigorous debate has ensued among academics, educators and policy makers on the most efficient way of making earth education meaningful and relevant to the society.

At present, spectacular developments in instrumentation enable exploration of the earth from the nanoscale to remote observations of the whole earth from outer space. In the domain of time, isotopic geochemistry makes age-dating possible on scales varying from days to billions of years. Deep-earth tomography can reveal the earth's internal structure in unprecedented detail. Thanks to telemetry, atmospheric events, rainfall infiltration and changes in ocean levels can be monitored in real time from remote locations. Modern computers enable compilation, analysis and visualization of enormous quantities of field data and quantitative analysis of complex earth systems through mathematical models. Aided by these, basic research in earth sciences flourishes, pursued by the most curious minds.

Yet, earth sciences are, in their essence, historical. At their best they provide explanations for what has already happened. But, their ability is noticeably limited when seeking to extrapolate the past into the future. The most powerful computer models can identify possible patterns of behaviour of earth systems, but cannot predict what will actually happen. The earth, while being amenable to comprehension with numbers, simultaneously defies precise numerical description. In comprehending the earth, numbers and descriptive thinking go hand in hand.

Following the Second World War, democracy is the preferred form of governance among nations, bestowing fundamental privileges on all citizens, including right of access to vital natural resources. In this atmosphere, protecting the environment, preventing endangerment of species, and minimizing loss of life and property from catastrophic natural events are ideals that are aspired by all nations. This new mindset has had a profound influence on how society perceives the earth. The earth's natural resources are no more perceived as commodities to be exploited for maximum profit, but as common good to be managed for sustaining the present, and preserved for future generations. Consequently, focus has shifted to the earth's near-surface, the human habitat. Applied earth sciences is directing attention to interactions among the atmosphere, the hydrosphere, the lithosphere and the biosphere.

This focus could be best expressed as the venture of adapting civilized human sustenance to the functioning of the hydrological cycle. The hydrological cycle, simple to comprehend, yet enormously complex to quantify, controls the earth's erosional, geochemical and nutrient cycles. Together, these four cycles make the earth an extraordinary object in the cosmos, both in regard to geologic structure and the existence of life. The hydrological cycle provides a framework uniting all earth knowledge.

Science is ethically neutral. Society may use the output from science, beneficially or otherwise. Wise use of scientific knowledge entails social judgement. Science cannot create policies, even as policy cannot be credible without science input. Ideally, they need to be in harmony. In this coming together of science and policy some of the greatest challenges are being faced by the world's nations. This coming together of science and policy completes the ultimate ideal of integrating all human knowledge into a single whole.

In essence, our technological civilization is being pulled by two opposing forces. Spectacular advances in the physical and biological sciences offer unprecedented hopes of improving the quality of life and extending longevity for all humans. Yet, these same technological actions threaten the subtle balances existing among the earth's natural resource systems and biological habitats. Clearly, expectations of modern technology have to be moderated by nature's constraints. Technology has to adapt to nature in its service to society.

Elements of earth education

Given the foregoing, the goals of earth education are:

- Continued development of earth knowledge through curiosity-driven basic research.
- Training and maintaining a cadre of personnel in the earth sciences and engineering to meet the needs of academia, industry, government and nongovernmental organizations.
- Introducing all students not majoring in the earth sciences to essential facts about the earth.
- Educating students in elementary schools and high schools about the earth, its environment and ecological conditions, and
- Enlightening the public at large about the earth, and the interplay between natural resources and the environment.

Over the past two decades, there has been a decline in undergraduate and graduate enrolment in the earth sciences and engineering, partly due to the prospects of better career opportunities in other fields such as information technology, biotechnology and business, and partly due to exciting intellectual developments in physical and biological sciences. Concomitantly, universities have been unable to meet the manpower needs of industries and developmental agencies that depend on earth knowledge. In response to these changing conditions, universities have been restructuring themselves, eliminating small and specialized units, and forming larger interdisciplinary entities. The larger units cut across boundaries between the atmosphere, the oceans, hydrology, soils, ecosystems and geology, with all of them drawing upon a common base of geophysical, geochemical and mathematical tools. In research universities, these evolving structural changes are supported by collaborative research among scientists from many different fields, universities and countries.

The knowledge base that is currently available from many specialized fields is invaluable, although these fields are giving way to new interdisciplinary areas. This specialized knowledge encapsulates detailed understanding of the physical and chemical behaviour of individual components of the earth system. Integration of disciplines has to occur through the integration of knowledge of the components. Consequently, as educational units are restructured, the goal of teaching is to preserve existing knowledge and present it in a broader context, to answer questions pertaining to interconnected earth systems. The focus is on understanding how the earth functions and how the existing knowledge-base can help in that understanding. The challenge is to develop curricula that will capture the essential aspects of earth systems and their interactions. This goal is achievable if the earth is recognized as the common denominator.

The topic of interdisciplinary communication raises the issue of quantification. Earth systems function according to immutable laws of nature, and these laws provide the basis for quantification. However, because of complicating factors such as heterogeneity, various spatial and temporal scales of interest, difficulty of access to observation and uncertainty of forcing functions, earth systems inherently defy precise quantitative description. Practically, lack of quantitative precision is to be compensated by judgment arising from intuitive, observational experience. In understanding the earth, the goal is to make as precise quantitative observations as is possible, analyse the data with the best available conceptual – mathematical tools, and interpret the results with judgement stemming from intuitive experience. Thus, quantitative science and descriptive science compliment and not negate each other. Analogous to the challenges of balancing theory and experiments in the physical sciences, the challenge in the earth sciences is to balance the application of mechanics, thermodynamics and mathematics with the ability to decipher history based on descriptive observations.

In the preface to his celebrated work, *Analytic Theory of Heat*, Joseph Fourier stated, 'Profound study of nature is the most fertile source of mathematical discoveries'. Fourier himself embarked on the study of heat so as to understand the role of heat in the functioning of the solid earth as well as the oceans, the atmosphere and deep space. Descriptive observations inspire questions, to answer which, one has to devise necessary instruments and draw upon knowledge from physics chemistry and mathematics. Earth education is incomplete if this synergism is overlooked. This synergism requires that earth scientists, regardless of their specialization, have the ability to place their work in context within broader questions of earth systems.

Ultimately, prospects of a career with reasonable monetary compensation motivate a majority of students. Thus, the health of earth education in the universities is dependent on career opportunities in the industry, academia, research institutions, the government and elsewhere. Invariably, industrial manpower needs fluctuate. Although the educational mission of universities requires that a stable, core curriculum be maintained, it is necessary that curricula be flexible to meet the changing needs of the industry. In research universities this flexibility is often achieved by incorporating research problems into evolving courses. Another way to achieve flexibility is to periodically offer refresher courses for personnel who are already in service.

Achieving strong earth education in India depends on financially rewarding and intellectually exciting career opportunities. Over the past two decades, India has witnessed exceptional economic growth and there is optimism that India could soon become a world economic power. To make this optimism a reality, India must make wisest use of its land, water, mineral and ecological resources. However, the country lacks a coherent water policy, and land development is occurring at a feverish pace to accommodate the needs of a rapidly growing economy. Continued economic growth will only impose greater stress on the already stressed earth resources. To eradicate poverty and achieve economic prosperity, India has to manage its water and natural resources with sophistication. To achieve this, India requires the services of a substantial number of trained people from all branches of earth knowledge.

Through most of the 20th century, emphasis in technological societies has been on extracting natural resources, harnessing rivers and streams, and disposing untreated industrial wastes. Little consideration was given to monitoring earth resource systems, either to track resource depletion or to observe environmental degradation. Resource developers had little inclination to invest in monitoring. However, systematic monitoring of earth resource systems and the environment is integral to and a permanent part of adaptive management strategies of the future. Design and maintenance of such monitoring systems, data storage, retrieval, and dissemination and timely detection of adverse, unacceptable impacts will become the responsibility of governmental agencies because resource developers will have little inclination to invest in such institutions. The creation of such institutions must be expected to open up new career opportunities in earth sciences and engineering.

In modern technological society, it is unrealistic to isolate science and technology from law and policy. In a finite earth subject to an unknowable future, vital earth resources have to be shared among all segments of the society. It is impossible to identify a unique optimization strategy that can satisfy all. Inevitably, compromises have to be made. Arriving at a best possible strategy of resource management lies in the domain of human judgement. Society has to make such judgements based on the best information that science can provide. For this reason, instruction in the philosophical, ethical and practical connections between science and policy has to be an inherent part of earth education. Here, it is pertinent to mention the 6th century Roman Law concept of *jus gentium*. In classifying property, this concept makes a distinction between natural elements (for example, air, water, sea) that are vital for the sustenance of all humans and so cannot be privately owned, and other things that can be privately owned. Accordingly, common property that belongs to all comes under the law of all peoples (*jus gentium*), as opposed to *jus civile* or civil law, which governs private property. The doctrine of public trust is derived from the tenet of *jus gentium*.

An informed citizen is central to a successful democracy. Citizenship training starts in elementary schools and continues through high school to university education. Outside of formal education, the better informed a citizen is, the more credible will his/her contribution would be to decision-making. In schools, earth education, both its science and socials aspects, will perhaps be achieved credibly in the format of geography, which integrates physical and human elements. At the undergraduate level, courses related to the earth would help in providing a balanced liberal education to non-majors. The education of the general citizen in earth-related matters commonly occurs through news media and television documentaries. These could be augmented by informative brochures and pamphlets distributed by appropriate public agencies devoted to earth resources. Additional benefits could arise from public lectures, forums and panel discussions on timely topics.

Earth education in India

In the aftermath of the tsunami tragedy of 26 December 2004, Balaram[1] addressed the status of earth sciences in India. Some of his editorial observations are worth reconsidering.

First, public perception of science is largely influenced by physics and physicists, globally and in India, in particular. Implicit in this observation is the recognition that although physics, chemistry and mathematics constitute essential tools for understanding the earth, questions about the nature of the earth and its functioning exist in their own right, transcending these tools.

Second, the study of earth sciences in India is at its lowest ebb. This is evidenced by dull, descriptive teaching of courses untouched by the excitement of modern science, lack of enrolment of students seeking earth science as their prime choice, research output lagging behind international levels and a distinct lack of presence of earth sciences community in major institutions. This assessment of earth sciences in India must be a matter of grave concern because India's economic prosperity and social well-being are at great risk if the country's earth resources (land, water, mineral resources and ecosystems) are not managed properly. Management of earth resources requires skills and techniques that are different from those of physical and biological sciences.

Third, whereas earth sciences is currently a melting pot of disciplines, India's own institutions are notably insular. This observation captures the sentiment expressed at the beginning, that earth knowledge is in a state of transition due to the evolution of that knowledge. The days of mutually insulated specialized disciplines have given way to collective, multi-disciplinary understanding of interconnected earth systems on various spatial and timescales. This need for collective effort is not motivated merely by intellectual curiosity. The civilized future of our technological society vitally depends on such a collective, broad-based approach.

Concluding remarks

Since independence, India's educational focus has slanted towards technology, commerce and more recently, law. This is evidenced by India's reputed institutes of technology, regional engineering colleges, business schools and national law schools of excellence. Compared to these, earth education has received lesser attention.

India is now at the onset of impressive economic growth. There is optimism that economic growth will pave the way for poverty reduction and improvement in the condition of all Indians. Yet, this optimism will come to nought if the country's water, land and ecological resources are not properly managed. The Indian subcontinent has experienced continuous human habitation for millennia. This, combined with India's population growth, has led to significant stresses on the natural resources base. Even to sustain the economy at the present levels and assure equitable distribution of water, India has to manage its water and land resources far better than what it does now. Growth beyond existing levels will inevitably demand additional quantities of water, construction materials and land. Management is the key to meeting these demands. Such management will require adequately funded, new institutional infrastructure and personnel trained in earth knowledge.

For a healthy economic future, India has to draw upon earth knowledge at a level that is on par with physical sciences, business and law.

To mobilize earth knowledge, there has to be a concerted effort by the common citizen, teachers in elementary schools and the universities, various industries, the academies of science and the government to address issues of earth education. India is already facing a situation in which its academic institutions are unable to meet manpower demands in earth sciences and engineering. The short-term solution to this problem may be to attract, through adequate incentives, talented individuals from other fields, who would be willing to direct their skills to understand the earth. Considering the growing awareness around the world of a shrinking planet, inducing these individuals to take interest in the earth may indeed prove rewarding to all concerned.

1. Balaram, P., *Curr. Sci.*, 2005, **88**, 5–6.

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Fixed dose combinations: Rational or irrational?

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Fixed dose combinations (FDCs) are combinations of two or more drugs present in a dosage form. Rational drug therapy means the use of the right medicine in the right manner (dose, route, frequency of administration, duration of therapy, etc.) in the right patient at the right cost and at the right time. In an effort to initiate rational drug therapy, the World Health Organization (WHO) introduced the concept of an essential drugs list in 1977 and it updates the model list every two years[1]. Subsequently after two decades in India, the Delhi Society for Promotion of Rational Use of Drugs (DSPRUD) was formed to promote the rational use of drugs. The 15th list of essential medicines by WHO has only about 25 FDCs[2]. However, it is staggering to find that over 80,000 formulations are sold in the Indian market, which include several FDCs and other single drug formulations.

Although various opinions have been expressed regarding the rationality of FDCs, there are only a few studies taken up to find the rationality of FDCs. One such study carried out in M.L.N. Medical College, Allahabad, has elucidated the rationality of FDCs prescribed by doctors using the WHO list of essential medicine[3].

There has been an alarming increase in irrational FDCs in the recent past and pharmaceutical companies manufacturing these FDCs are luring physicians to prescribe their products even when they