tracts certain types of software development to Indian firms. Other American industries may also be willing to take advantage of India's topnotch research establishments, which could provide needed research and development at significantly reduced costs. But as mentioned before, US industries, like their Indian counterparts, are unlikely to invest in research until and unless they are assured that the outcome of that investment – intellectual property – will be adequately protected.

In conclusion, I would like to reiterate that the US supports strong IPR protection. As outlined previously, this support comes more from a desire to protect researchers' interests, rather than political interests. The US firmly believes that strong IPR protection is beneficial to both industry and consumers in both developed and developing nations. International collaboration is one of the many activities that will flourish under improved IPR protection.

Haldane's dilemma and its relevance today

Krishna R. Dronamraju

Introduction

THE scientific and intellectual eminence of John Burdon Sanderson (JBS) Haldane is such that we are indeed fortunate to be holding this symposium under his name. The very mention of his name evokes scientific excellence and its benefits to humankind. Indeed, by honouring Haldane, we are honouring ourselves.

It has been said that it is only by standing on the shoulders of giants that we can see far. J. B. S. Haldane was one of those giants. Even some thirty-two years after his death, Haldane's direct impact can be readily seen from the long list of citations to his publications in the *Science Citation Index* and similar compilations today. Both directly and indirectly, Haldane's world-wide influence had been quite significant ever since his first scientific paper – in collaboration with his father John Scott Haldane in respiratory physiology – was published in 1912. To this day, he remains one of the most quoted scientists of the twentieth century. He left so much unfinished work when he died in 1964 that his manuscripts continued to be discovered and published posthumously. The last publication was a book on science fiction called *A Man with Two Memories*.

Haldane in India

J. B. S. (or Jack) Haldane was born in Oxford, England, on November 5, 1892 and died on December 1, 1964, in Bhubaneswar, India. He received formal education at Eton and Oxford, studying mathematics and classics, but received no academic qualification in science. However, his early scientific education was provided at home by his father, distinguished Oxford physiologist John Scott Haldane. The younger Haldane successfully (and successively) pursued research in physiology, genetics, biochemistry, statistics, and biometry at several English universities including Oxford, Cambridge and London. In addition to his brilliant scientific contributions, Haldane became famous for his outstanding popularization of science in the lay press. Furthermore, he took part in politics also, especially during the 1930s and the '40s, writing and speaking extensively on the marxist philosophy. However, when he migrated to India in July, 1957, Haldane largely gave up his political activities, taking up a new interest in Hinduism and Indian philosophies. It was during that period, from 1957 until his death in 1964, that I came to know him intimately as a pupil and a colleague in Calcutta and Bhubaneswar. He adopted an Indian lifestyle – wearing Indian style clothes, eating only vegetarian food, studying Hindu classics and mythology, etc. All these distinguishing qualities – intellectual, political, philosophical, and personal – combined with his highly interesting family background, made Haldane a most interesting character for biographies.

I have previously described the biographical details of Haldane's life and work in numerous books and papers[1–9]. These may be consulted for further details. Haldane himself left a highly informative autobiographical sketch which mentions his life in India and his association with myself and others[10].

In India, Haldane was associated with three different institutions: Indian Statistical Institute in Calcutta (1957–61), Genetics and Biometry Unit of the Council of Scientific & Industrial Research in Calcutta (1961–

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62) which he tried to establish unsuccessfully, and the Genetics and Biometry Laboratory of the Government of Orissa in Bhubaneswar (1962–64). The topics covered by Haldane and his associates included human genetics, plant breeding, biometry, animal behaviour, and theoretical or mathematical population genetics. In addition to these activities, he lectured widely and contributed popular articles to the lay press.

Intellectual hybridization

A biographical analysis of Haldane's intellectual growth and achievements indicates that because of his extensive knowledge of several branches of science he was able to create new concepts by synthesizing ideas and concepts from several existing disciplines. I have called this process[5] 'intellectual hybridization'. Examples include the foundations of 'population genetics', 'biochemical genetics', especially the gene–enzyme concept, 'immunogenetics', 'gene mapping', 'molecular biology', 'behaviour genetics', etc. Haldane played a pioneering role in all these fields. In his classic, *The Causes of Evolution*, Haldane[11] was the first to analyse the evolutionary consequences of altruistic genes in populations (e.g. honey bees) which later led to the founding of 'sociobiology' by W. D. Hamilton and E. O. Wilson. It was also in that same book that Haldane estimated the first human mutation rate (for haemophilia). To the *foundation of human/medical genetics*, Haldane's contributions were so important that he had no parallel[5]. These are but a few examples which I have selected from Haldane's numerous scientific contributions.

Science and ethics: Haldane's dilemma

Although Haldane had made several profound contributions to physiology, biochemistry, genetics and other sciences, he may well be remembered by posterity for his advocacy of an adequate ethical framework which would be able to incorporate new developments in science and technology, especially genetic engineering. In his book *Daedalus, or Science and the Future*, Haldane[12] was the first to raise a number of ethical dilemmas which are the focus of attention in biotechnology today. His original work has been recently reprinted in my book: *Haldane's Daedalus Revisited*.

In 1923, Haldane had already foreseen the kind of disasters – both in war and peace – which resulted in this century as a consequence of technology.

Genetic engineering

Haldane's predictions in *Daedalus* include the widespread use of *in vitro* fertilization in human societies, resulting in the production of a large proportion of test-tube babies each year, artificial transmutation of the genetic material, and practice of eugenic selection to produce individuals with exceptional skills in music, art, sports, sciences and other abilities.

Haldane's scientific predictions go hand-in-hand with dire predictions of social and ethical disaster if their applications are not made with a great deal of caution. Advances in reproductive biology and genetic engineering today have already seen some misapplications or adverse impact of certain applications. Foetal selection and infanticide have been practised in certain communities. Products of genetic engineering such as high milk-yielding cattle and various crops have not met with social acceptance as had been anticipated. There is also continuing fear that genetic engineering might be used for the purpose of developing weapons of biological warfare. For this reason, some developing countries have expressed reluctance in participating in collaborative research which involves research on DNA polymorphisms.

Genetic engineering and other aspects of modern biotechnology have raised a host of new problems in trade and international relations. There is no general agreement about the nature of patenting of biological materials and processes. Most countries have had no domestic legislation regarding intellectual property rights until recently, but, under the GATT agreement this situation is expected to be remedied soon. There continue to be profound differences among individuals and nations regarding the patentability of the human genome. *Patenting of naturally-occurring* DNA sequences should not be allowed (as some in the USA have suggested). Specific processes and products may be patentable under certain conditions.

Shared credit for intellectual property rights presents an especially difficult problem. Among other problems are the rights of the indigenous people such as the farmers who pioneered agricultural practices long time ago, utilization of raw materials, and parallel development of various practices and products. Technological progress proceeds at a different pace in each country. This depends on several factors: financial resources, level of technology and education, government policies and domestic business and intellectual climate. There is a basic question of ethical judgement – whether a few technologically advanced countries can appropriate world's resources and claim intellectual property rights which would be detrimental to the rest of the world. This is especially relevant to the large number of developing nations which contain many of the raw materials and are populated by a majority of the world's population.

Problems with new technologies

In spite of the fact that new technologies usually creat new benefits, a note of caution is warranted. Importan

lessons can be learned from the experience of technologically advanced nations. At least four instances can be cited: (a) If new technologies are introduced too quickly, increased unemployment may be the result. Gradual transfer or creation of technology should go hand-in-hand with extensive training and literacy programs. (b) Technology transfer (or sharing), by its very nature, creates new social values and standards which often conflict with traditional beliefs and traditions. It may pose a threat to indigenous economies and social systems, thus turning the whole matter into political controversy. (c) Biotechnology involving genetic engineering and reproductive biology may be misused on the one hand (e.g. aborting a foetus for trivial reasons) or may lead to new social problems; potential carriers of genetic diseases may face difficulties in obtaining education, employment and medical or life insurance, and (d) New technologies may occasionally pose risks for public (or individual) health by means of biological or chemical contamination of the environment or by increasing stress levels. A special problem may be created by the long-term consequences of human gene therapy. The long-term carcinogenic possibility of recombinant DNA, when introduced into the cells of patients, is not yet known.

The genetic revolution predicted by Haldane has arrived. It came twenty years later than he thought. We should consider ways of resolving Haldane's dilemma. Instead of stumbling into problems created by technology, we should have a deliberate coordinated programme to anticipate potential problems of impending technology and find ways of resolving them before they become active crises. This is one of the lessons we have learned from the experience of USA, Europe, and other industrialized parts of the world.

Anticipating the consequences of technology

Educational curricula should include courses on the impact of technology and its potential consequences. But this is not the case in many countries. Coordinated and planned introduction of technologies should be preceded by simulated computer analyses of potential adverse impact, impact of new biological, chemical or other products on the health of future generations (such as the projected contamination levels of air and water), public education of various issues by using television and other media, projected costs and available resources for coping with the consequences, anticipation of adequate employment and training strategies, and choice of alternative technologies based on cost/benefit ratio, etc. These decisions should be based on long-term considerations and not on short-term benefits.

We honour Haldane by remembering this duality which he had emphasized long ago. On the one hand, we cannot go very far without the benefits of science and technology in today's world. On the other hand, we should find ways of anticipating and coping with the economic, biological and other consequences of new technologies. In both situations, we will surely benefit by following Haldane's admonition.

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