applied to multiple climate models is needed. This effort has been initiated for the modelling of climate effects from stratospheric aerosol injections[48]. Finally, but not the least important, the possibility of SRM geoengineering is by no means an excuse of continued fossil-fuel emissions. A combined emission mitigation and geoengineering strategy is what we might want to seek to avoid dangerous climate change and reduce our dependence on fossil-fuel emissions[49].

1. Solomon, S. D. *et al.*, *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2007.
2. Angel, R., *Proc. Natl. Acad. Sci. USA*, 2006, **103**, 17184–17189.
3. Early, J. T., *Jbis – J. Br. Interplanet. Soc.*, 1989, **42**, 567–569.
4. Seifritz, W., *Nature*, 1989, **340**, 603.
5. Struck, C., *Jbis – J. Br. Interplanet. Soc.*, 2007, **60**, 82–89.
6. Latham, J., *Nature*, 1990, **347**, 339–340.
7. Latham, J. *et al.*, *Philos. Trans. R. Soc. London, Ser. A*, 2008, **366**, 3969–3987.
8. Akbari, H., Menon, S. and Rosenfeld, A., *Climatic Change*, 2009, **94**, 275–286.
9. Evans, J. R. G., Stride, E. P. J., Edirisinghe, M. J., Andrews, D. J. and Simons, R. R., *Climate Res.*, 2010, **42**, 155–160.
10. Crutzen, P. J., *Climatic Change*, 2006, **77**, 211–219.
11. Budyko, M. I., *Climate Changes*, American Geophysical Union, 1977.
12. Keith, D. W., *Nature*, 2001, **409**, 420.
13. Royal Society Report, London, 2009.
14. Soden, B. J., Wetherald, R. T., Stenchikov, G. L. and Robock, A., *Science*, 2002, **296**, 727–730.
15. Held, I. M. *et al.*, *J. Climate*, 2010, **23**, 2418–2427.
16. Matthews, H. D. and Caldeira, K., *Proc. Natl. Acad. Sci. USA*, 2007, **104**, 9949–9954.
17. Govindasamy, B. and Caldeira, K., *Geophys. Res. Lett.*, 2000, **27**, 2141–2144.
18. Caldeira, K. and Wood, L., *Philos. Trans. R. Soc. London, Ser. A*, 2008, **366**, 4039–4056.
19. Rasch, P. J., Crutzen, P. J. and Coleman, D. B., *Geophys. Res. Lett.*, 2008, **35**, L02809.
20. Lunt, D. J., Ridgwell, A., Valdes, P. J. and Seale, A., *Geophys. Res. Lett.*, 2008, **35**, L12710.
21. Irvine, P. J., Ridgwell, A. and Lunt, D. J., *Geophys. Res. Lett.*, 2010, **37**, L18702.
22. Bala, G., Duffy, P. B. and Taylor, K. E., *Proc. Natl. Acad. Sci. USA*, 2008, **105**, 7664–7669.
23. Andrews, T., Forster, P. M. and Gregory, J. M., *J. Climate*, 2009, **22**, 2557–2570.
24. Bala, G., Caldeira, K. and Nemani, R., *Climate Dyn.*, 2010, **35**, 423–434.
25. Ban-Weiss, G. A. and Caldeira, K., *Environ. Res. Lett.*, 2010, **5**, 034009.
26. Eby, M. *et al.*, *J. Climate*, 2009, **22**, 2501–2511.
27. Govindasamy, B., Thompson, S., Duffy, P. B., Caldeira, K. and Delire, C., *Geophys. Res. Lett.*, 2002, **29**, 2061.
28. Matthews, H. D., Cao, L. and Caldeira, K., *Geophys. Res. Lett.*, 2009, **36**, L10706.
29. Cao, L., Bala, G., Caldeira, K., Nemani, R. and Ban-Weiss, G., *Proc. Natl. Acad. Sci. USA*, 2010, **107**, 9513–9518.
30. Boucher, O., Jones, A. and Betts, R. A., *Climate Dyn.*, 2009, **32**, 237–249.
31. Gedney, N. *et al.*, *Nature*, 2006, **439**, 835–838.
32. Betts, R. A. *et al.*, *Nature*, 2007, **448**, 1037–1035.
33. Govindasamy, B., Caldeira, K. and Duffy, P. B., *Global Planet. Change*, 2003, **37**, 157–168.
34. Bala, G. *et al.*, *Climate Dyn.*, 2010, **37**, 915–931.
35. Robock, A., Oman, L. and Stenchikov, G. L., *J. Geophys. Res.*, 2008, **113**, D16101.
36. Jones, A., Haywood, J., Boucher, O., Kravitz, B. and Robock, A., *Atmos. Chem. Phys.*, 2010, **10**, 5999–6006.
37. Ricke, K. L., Morgan, G. and Allen, M. R., *Nature Geosci.*, 2010, **3**, 537–541.
38. Bala, G. and Nag, B., *Climate Dyn.*, 2011 (in press).
39. Braesicke, P., Morgenstern, O. and Pyle, J., *Atmos. Sci. Lett.*, 2011, **12**, 184–188.
40. Tilmes, S., Garcia, R. R., Kinnison, D. E., Gettelman, A. and Rasch, P., *Geophys. Res. Lett.*, 2009, **114**.
41. Tilmes, S., Muller, R. and Salawitch, R., *Science*, 2008, **320**, 1201–1204.
42. Heckendorn, P. *et al.*, *Environ. Res. Lett.*, 2009, **4**, 045108.
43. Gu, L. H. *et al.*, *Science*, 2003, **299**, 2035–2038.
44. Niyogi, D. *et al.*, *Geophys. Res. Lett.*, 2004, **31**, L20506.
45. Oliveira, P. H. F. *et al.*, *Tellus B*, 2007, **59**, 338–349.
46. Robock, A., *Bull. Atom. Sci.*, 2008, **64**, 14–18.
47. Rasch, P. J., *Environ. Res. Lett.*, 2010, **5**, 031001.
48. Kravitz, B. *et al.*, *Atmos. Sci. Lett.*, 2011, **12**, 162–167.
49. Wigley, T. M. L., *Science*, 2006, **314**, 452–454.

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Corporate education in natural sciences: a professional approach for universities

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The joint education panel of the Indian Academy of Sciences, the Indian National Science Academy and the National Academy of Sciences, India has pointed out that the enormous potential for India to become a leading knowledge power can be realized only if our younger generation has opportunities for all-round good education and training, especially in science and technology[1]. Though the society around our universities has changed and evolved under the selective pressures of a liberalized economy, the intellectual environment of the university has probably declined[2]. We have produced more unemployable graduates, as we treated universities more as a place where students get credentialed and teachers educate without much concern for societal problems/issues or for the economic future of students.

The Yashpal Committee of 2009 on renovation and rejuvenation of the higher education system in India has given several suggestions[3]. The position paper of the science academies[1] emphasizes the need for making higher education more relevant to the changing needs of society, through massive investments along with well-planned radical changes. Two of the necessary transformations are in: (i) how we train our young minds, and (ii) improvement in the quality and quantity of teachers. The need for change in our education system, particularly science education, is imperative. Narasimharao[4], discussing the relevance of corporate education centres in tertiary education institutes, observes that it is essential to make our universities complete and broad-purpose organizations without limiting their purpose. In the whole process, the basic requirement is that the universities should develop the ability of reaching out to society, with their students bringing both scientific knowledge and professional skills to the workplace. We discuss these aspects to explore the various options available with us while making corporate education as a base.

Education in natural sciences

Role of university as the 'conscience of society'

There is much debate on the role of the university as the 'conscience of society' and the appetite of the knowledge economy for qualified workers and pragmatic forms of knowledge[5]. We need to analyse this debate, as we have even educated Ph D students to replace ourselves in academic institutions and (purposely?) not educated them for the real world of life sciences outside universities[6]. Over the years, the result is that these graduates have taken up jobs that are not relevant to their training or they have become more and more unemployable. Relevant education and training in the natural sciences depends on the way we relate knowledge production to societal use.

Broader role of corporate education

There is a need to protect the traditional role of universities while accommodating the economic forces of society. Concepts like corporate education can help us in this attempt[4]. One of the strategies suggested is to define corporate education in universities in broader terms covering economic, social and cultural developments; to see it in totality. The importance of such an approach may be better realized when we consider the fourteen 21st century challenges that the National Academy of Engineering has chosen[7]. All these can be related in one way or the other to natural sciences. The increasing number of applied courses and management courses in science subjects in India indicates the demand for students of physics, chemistry, biology and mathematics to be credentialed with relevant practical orientation, similar to those in engineering and technology. As in Pasteur's quadrant for research and development[8], the focus should be on use-inspired education where both fundamental understanding and application-oriented use are integrated.

New paradigm of knowledge production and the role of universities

In the transition towards a knowledge economy and knowledge society, universities need to produce more knowledge, relevant knowledge, and also take responsibility for its transfer. It cannot be done in isolation as in the old paradigm of scientific discovery of theoretical or experimental science, with its internally driven taxonomy of disciplines and with autonomy of scientists and their host institutions, the universities. This is being superseded by a new paradigm of knowledge production that is socially distributed, application oriented, transdisciplinary and subject to multiple accountabilities[9]. Universities need to play multiple roles with close linkages with all the stakeholders of higher education. For instance, relevant knowledge from universities may be integrated into a particular section of the society through outreach programmes and in turn, universities can integrate the tacit and practical knowledge of the people into their basic knowledge.

Developing a successful professoriate

Four 'interlocking functions' are necessary for a successful professoriate or university, namely (i) basic research, (ii) placing discoveries within a larger context, (iii) teaching and communication, and (iv) application of knowledge[10]. The need for integration of these functions may also be reflective in the trend to recognize research institutes as 'deemed universities'. None of the research institutes even fulfil the classical requirements of a university, having a concourse of students and teachers in many diverse disciplines as defined by the Yashpal Committee[3]. As Lakhotia[11] puts it, the present mess in the system of higher education cannot be solved by the research institutes 'breaking away' from the university system. There is a need for thinking beyond the well-drawn boundaries between research institutes and universities not only to enable the production of manpower with a broad vision and professionalism, but also to utilize the expertise available at various institutions in an integrative fashion (Figure 1); 'industry' can be replaced with any other stakeholder of higher education in Figure 1. It is also necessary that we introduce innovative concepts, such as corporate education, outreach programmes, triple helix, mode2 and sustainable higher education to make this happen.

Developing professional skills in natural sciences

The need for a new approach

The emergence of new knowledge-based economies has placed increasing emphasis on the development of professional skills. It is postulated that Master's programmes could produce graduates who provide the same level of 'expertise and leadership' as professionals do in other fields[12]. We can extend this to undergraduate education in science as well. Sitaramam and Sauna[13] question whether we can overcome the mindset that science and industry are different and whether we can bridge the gap between the intellectual frontiers of pure science and the transmission of specific skills for the job market in biological sciences or life sciences. They also observe that both parents and students are more inclined towards a professional course.

The position paper of the science academies[1] rightly states that the poor structure of B Sc programmes, compounded by poorer teaching and facilities, fails to prepare the students for gainful employment or to launch a promising academic career. This is the case even in higher degrees in science and technology, as is evident from the estimation by the National Council of Applied Economic Research – there are only 10% employable graduates from the 12 million science and engineering graduates, including

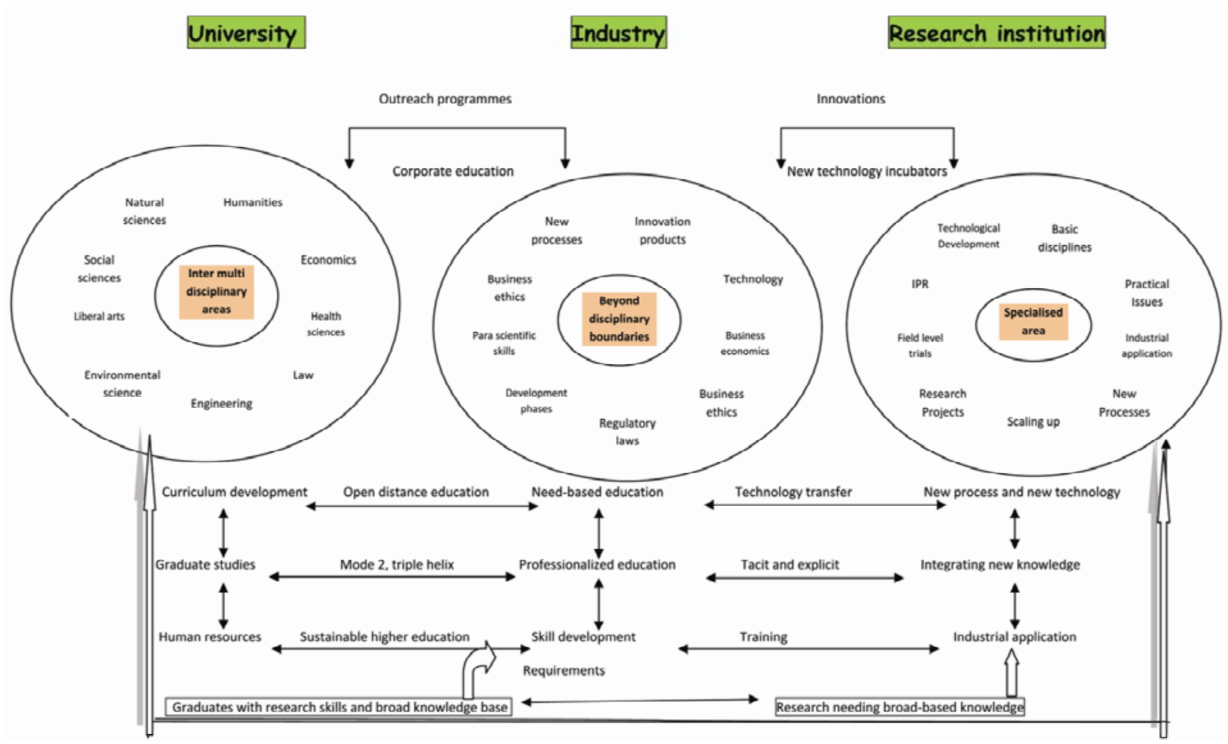

Figure 1. Need for integration among university–research institution-industry.

2 million postgraduates and 100,000 Ph Ds. The position paper suggests multiple options for students coming out of the 10 + 2 schooling system in the science stream; the main focus here is the structure of the teaching programmes. However, for professionalizing science education we need more approaches and must also focus on the treatment of the subject. For instance, there are many MBA programmes in science being offered. A biotechnology management course can be a specialization in a general management course for a biology graduate; it should not be a broad degree for a management trainee[11].

Professional requirements in natural sciences

As we apply science and technology principles in every walk of life, it is obvious that its education and training is needed in various spheres. For instance, Robbins-Roth[14] collects 22 career descriptions for science graduates ranging from public policy to investment banking, from patent examination to broadcast science journalism. If some of the skills required for these professions can be integrated in the training of our graduates, without compromising on the necessary basics, these science degrees can become an attractive route to one of the many alternative careers in life sciences. Narasimharao[15] discusses the development of human resources in biotechnology, taking into account the societal demands covering community development and industries. The report of the National Research Council, USA studies the need for a Master's education in all natural sciences covering various sectors of the society, where science professionals can make an impact[16].

Training science graduates with a professional orientation and covering various sectors of the society will help in alleviating the problem of 'unemployable' science graduates and cases of students taking up science as a second and out-of-compulsion choice to professional engineering/medicine programmes. This does not mean that we turn our science education programmes into trade schools or vocational schools. The purpose is to balance between the three approaches of Pasteur's quadrant[8] according to the societal needs and demands[17]. The professional programmes do not displace traditional Master's programmes but fulfil the needs of students who require a different graduate experience for the workplace: for instance, large firms needing graduates with knowledge of financial and industrial mathematics; biotechnology companies needing middle-level managers with scientific knowledge and broader business skills; services corporations needing employees with depth in science and customer skills, and government agencies (particularly military, intelligence, security, various science-based departments) that have an increasing need for science and technology-savvy staff. However, these should not be 'science plus' programmes; that is, they should not include separate courses focusing on professional skills, but provide skill development through scientific training itself.

Broadening the horizons of scholarship

While proposing 'institutional innovation systems' for promoting concepts like corporate education, Narasimharao[4] points out that the change should come from within for its effectiveness and sustainability. This cannot be done easily as the faculty might consider their territories invaded and may feel that they have to protect their disciplines and the university.

New boundaries to scholarship need to be defined. Rangappa and Narasimharao (in a paper presented at the Pan Commonwealth Forum 6, Cochin, November 2010) discuss the development of strategies for successful science and technology programmes in open universities under three broad heads: (i) innovations, (ii) borderless education and (iii) approaches. Under innovations, we need to deal with technologies, pedagogies and the societal context. Borderless education may cover convergence of all systems, making disciplinary boundaries and education systems more porous, integrating traditional knowledge and modern knowledge, knowledge management and knowledge integration. For achieving these, we can follow different approaches like collaboration and networking (sharing of resources), outreach and engagement (scholarly engagement), sustainable education (balancing market forces), corporate education (triple helix) and skill development and engagement (community engagement).

Academics need to be trained in balancing both the economic and the traditional functions of a university. This is possible by integrating university activities, curriculum development and societal needs with outreach. The university outreach programmes in developing countries like India can play a vital role in community and regional industrial development. They will also help in tapping the explicit and tacit knowledge available with different stakeholders of higher education, including faculty, students, industry, non-profit organizations and government bodies[18]. Development of the corporate education concept in universities, with the ability to use the 'whole' university for the advantage of society, can force the faculty to collaborate more with the external world, wherein the theory and concepts of natural sciences are applied. This may help academics to bring the change from within for broadening the horizon of their scholarship.

Conclusions

Traditionally, the Master's degree in the natural sciences has tended to be single-discipline in orientation, an extension of undergraduate science education, and preparatory to the doctorate. This tradition needs to give way to new practices and mechanisms for integrating different disciplines, as there is a paradigm shift in science towards knowledge production with multiple accountabilities[9]. It has to be done through changes in our curriculum, reorienting our faculty and using recent developments in higher education systems such as outreach engagement, corporate education and open distance learning systems. We argue that professional programmes in science in general and in the natural sciences in particular can be prepared using these concepts.

1. Lakhotia, S. C. and Mukunda, N., *Curr. Sci.*, 2008, **95**, 1411–1420.
2. Balaram, P., *Curr. Sci.*, 2008, **94**, 153–154.
3. These suggestions include avoiding division between research bodies and universities, establishing a live relationship with the real world outside, making the walls of higher education institutions porous to hear the voices (of stakeholders) outside the system, avoiding compartmentalization and fragmentation of knowledge, integrating vocational and technical education, and learning across disciplines. Yashpal Committee Report, Report of 'The Committee to Advise on Renovation and Rejuvenation of Higher Education', 2009; http://www.education.nic.in/, accessed on 11 July 2009.
4. Narasimharao, B. P. R., In Discussion papers in social responsibility, 2010, vol. 1003, pp. 1–73; SRRNet, UK; www.socialresponsibility.biz
5. Jacob, M. and Heustrom, T. (eds), *The Future of Knowledge Production in the Academy*, Buckinghom Society for Research into Higher Education and Open University Press, 2000, p. 163.
6. Schuster, S. M., *Biochem. Mol. Biol. Educ.*, 2009, **37**(6), 381–382.
7. These challenges are: (i) make solar energy economical, (ii) provide energy from fusion, (iii) develop carbon sequestration methods, (iv) manage the nitrogen cycle, (v) provide access to clean water, (vi) restore and improve urban infrastructure, (vii) advance healthcare informatics, (viii) engineer better medicines, (ix) reverse engineer the brain, (x) prevent nuclear terror, (xi) secure cyberspace, (xii) enhance virtual reality, (xiii) advance personalized learning and (xiv) engineer the tools of scientific discovery. Monto, M., *Curr. Sci.*, 2010, **98**, 746–748.
8. Stokes, D. E., *Basic Science and Technological Innovation*, Brookings Institution Press, Washington DC, 1997.
9. Beerkens, E., *Sci. Technol. Soc.*, 2009, **14**(1), 153–175.
10. These four functions are: scholarship of discovery (basic research), scholarship of integration (placing discoveries within the larger context), scholarship of sharing knowledge (teaching and communication) and application of knowledge (as a reflective practice in which theory and practice inform each other). Boyer, E., *J. Public Serv. Outreach*, 1996, **9**(1), 11–20.
11. Lakhotia, S. C., *Curr. Sci*., 2005, **89**, 1303–1304.
12. They would do this because of the ability 'to use the products of scholarship in their work' and by being familiar with 'the practical aspects of emerging problem areas'. Tobias, S., Chubin, D. and Aylesworth, K., *Rethinking Science as a Career: Perceptions and Realities in the Physical Sciences*, Research Corporation, Tucson, 1995.
13. Sitaramam, V. and Sauna, Z. E., *Curr. Sci.*, 1996, **70**, 335–340.
14. Robbins-Roth, C., *Alternative Careers in Science: Leaving the Ivory Tower*, Elsevier Academic Press, San Diego, California, 2006, 2nd edn.
15. Narasimharao, B. P. R., *Soc. Responsibility J.*, 2010, **6**(1), 72–90.
16. National Research Council of the National Academies, *Science Professionals: Master's Education for a Competitive World*, The National Academies Press, Washington DC, 2008.
17. For instance, the Council of Graduate Schools, USA offers a variety of Master's programmes – the 'classical' programme is either a stepping stone to a Ph D or one with the characteristics of a classical programme; the 'applied' programme focuses on the application of the fundamentals of the discipline to a specific area of practice, but generally does not have a direct relationship to prospective employers; the 'professional' Master's programme often includes activities and relationships that cross the boundaries between departments and between the university and employers; the 'hybrid' programmes have characteristics of more than one of these three categories and can have a classical/applied mix or an applied/professional mix. Council of Graduate Schools, *Professional Master's Education: A CGS Guide to Establishing Programs*, Council of Graduate Schools, Washington, DC, 2006, pp. 43–44.
18. Narasimharao, B. P. R., *Sci. Technol. Soc.*, 2009, **14**(1), 119–151.

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