Strategies for Effective Science Education in the Present Century*

C. Vijayan**

Abstract

The present century continues to witness several emerging technologies often beyond the wildest of our imaginations. An unlimited content of information is available easily from resources all over the globe, packaged in a variety of extremely effective and unconventional styles of presentation. The shift of emphasis from the textbooks and the blackboard to the internet, virtual classrooms and multimedia is happening at a tremendous pace. The magnitude and speed of the information explosion of the present times re-emphasises the urgent need for building bridges across the huge gaps between information, knowledge and wisdom. This shifts our attention to the very basic purpose of education as an enabling, enriching and empowering technology, demanding focused efforts to evolve innovative strategies addressing the perspectives of the content and the style, the teacher and the taught, the enabling agencies and the public — all stakeholders. The emphasis is shifting towards learning to learn and uncovering and discovering the syllabus. Science education involves inspiring and motivating the student community at large, imparting theoretical as well as practical skills and highlighting the need for creative thinking and innovation. The proclaimed role of the educator, of opening up the students' eyes ('chakshurunmeelitam yena') towards glimpses of the ultimate reality, is particularly significant for science education. It is important to address the fundamental issue of the recent migration of excellent brains from science and science education towards greener pastures. Obviously, these pastures also are to be made sufficiently green! While waiting for this, we have also to evolve strategies within our reach to save the situation. The treasury of experience and wisdom of original thinkers on education and great teachers of the past and the present provides us specific examples, tested ideas and adaptable techniques to start with. We may have to struggle a bit, shaping bricks and polishing stones, which is an integral part of building up a monument. The fruits may be rewarding; but the charm and thrill of the adventure itself are worth the effort!

* This article was presented during the First Golden Jubilee Lecture Series-2011 at CIET, NCERT on 27 April 2011 delivered by Professor C. Vijayan, published by NCERT, New Delhi.

**Professor*, Department of Physics, IIT Madras

The NCERT means much more than a mere government office to me and several thousands of others from all over the country who have been supported and inspired through the prestigious National Science Talent Search Scholarship to pursue science for their education and career. Thus, I stand here in reverence and gratitude as I speak at the portals of the NCERT. Over the past several decades, this institution has been designing and developing appropriate methods for improving education and training in India as it has become a role model for the other developing nations in this noble endeavour.

The scenario has been ever-changing and the efforts have to continue to design specific strategies for education in general and science education in particular, adaptable to the perspective of the present century. The spirit of science education has perhaps been brought out in the most appropriate manner in the popular story of the legendary student of ancient India, *Shvetaketu*[1]. He returned home after completing his *Gurukula* education over a period of twelve years and stood before his father, *Uddalaka Aaruni*, declaring proudly that he had learned everything. His father asks him: "*Have you obtained that knowledge, which makes you understand all that has not been understood? Has your learning empowered you to think about all that has not yet been thought about?*" This question continues to be relevant to help us to retain our focus and perspective clear and sharp when we plan strategies for effective science education, even in the present century.

The Philosophy of Education — The Text as a *Pretext*

Education is actually the process of helping to learn — a process that enables, enriches and empowers. Learning is important while *learning to learn* is even more important. The teacher actually trains and encourages the students to learn by themselves. The aim of the teacher is to *uncover and discover* true scope and potential of the syllabus and then to transcend it. That is why it is often said that *a great teacher inspires.*

Our tradition has defined the teacher as *the one who removes the cataract of ignorance and reopens the eyes of the student* towards the light of knowledge, *enabling him to perceive a few glimpses of the ultimate reality that encompass everything*. The ultimate knowledge is stated to be *that, knowing which everything becomes understood*. This has special significance and meaning in the context of science education. Science is based on mathematical logic. A clear, straightforward and no-nonsense approach to learning and life at large can be inculcated by proper science education and training. Removing the cataract of ignorance and misconceptions is of crucial importance in science teaching. The universe we find ourselves in is pretty complicated as *Mother Nature likes to hold her pet secrets close to her heart.*[2] Science can unravel only some fraction of it all (though the fraction is expected to be a bit larger after the famous LHC experiments!). Yet, science is the only powerful enough tool for the survival of the species. This highlights the need for going beyond the text and inspiring the students to

transcend their limitations with a universal view with a larger perspective.

To give some specific examples from physics, the purpose of working out a particular numerical problem in a class on kinematics is not just to calculate when a particular car reaches its mundane destination under the given conditions, but to master the methods of dynamics at large. In fact it does not even stop there as most students are anyway not going to take up automobile engineering or even physics. It has the larger agenda of sharpening the students' intellect so as to develop their skill set for success in all human endeavours in their future.

The simple pendulum is a topic we learn in physics quite early. Then we complicate it by adding damped and driven motion. Now this becomes a very powerful paradigm to analyze extremely complex phenomena of oscillatory systems, regular and chaotic, in various branches of science, engineering, technology, medicine, finances and what not! A mastery of the study of partial differential equations, for example, enables one to model a great many dynamical systems that makes up our world – natural and manmade. Teachers and leaders of education will benefit by keeping such a balanced perspective — humble, factually correct, clear and logical — at the back of their minds if they wish to do their jobs properly.

Science Education in the Rapidly Unfolding Scenario

Several distinct features mark the horizon of science education of the present and the immediate future, most of which could not even be dreamt about before the turn of the century. For example, it is clear by now that a great amount of the process of education going to be out of the class room. The class room itself is going to be remarkably different. The ease of obtaining large amounts of authentic information in convenient formats such as multimedia[3] and simulation revolutionises the learning processes and prompts us to think beyond the textbooks and the blackboard have to take note of the rapid technological advances and make efficient and effective use of these in science education.

Today the student can enjoy high quality content in virtual classrooms provided by a choice of excellent institutions worldwide. This has made education truly 'global' as we are not limited to the wisdom of a single board or university at any remote geographical location. It has now become very easy to obtain the latest results of international research on education, to consult experts worldwide and to browse through the curricula of several universities over the globe. Free and easy access to several high quality e-books and other resources, obtaining information about and even purchasing books from sources all over the world and other similar facilities have changed the very outlook of education methodology[4]. The old adage of *learning only one fourth of the content from the teacher*[5] is going to attain its fullest significance in the years to come.

Churning the Milky Way of Information for the Nectar of Wisdom

However, the information explosion is a *genie released out of the bottle* and has to

be handled properly. Information *per se* is not knowledge, and knowledge *per se* is not wisdom. Bridges need to be built and better, chasms are to be filled thoroughly. As J. D. Everett had observed,[6] *"There is a great danger in the present day lest science-teaching should degenerate into the accumulation of disconnected facts and unexplained formulae, which burden the memory without cultivating the understanding."* It is the age-old fear of *loosing sight of the forest while examining the trees* in detail with all technical formalities. Here the question raised by T.S. Eliot becomes important[7]

"Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?"

Our attention should now focus on the very basic purpose of education as an enabling, enriching and empowering technology, and we have to plan focused efforts to evolve innovative strategies addressing the perspectives of the content and the style, the teacher and the taught, the enabling agencies and the public — all *stakeholders*.

Several initiatives are being taken up and strategies are being adopted in countries all over the world on improving the effectiveness of science education in the present times. The *American Association of the Physics Teachers*[8] and the *American Journal of Physics*[9] are just two examples from USA. The Organization for Economic Cooperation and Development (OECD) has been working on a project aimed to study innovation and change in Science Mathematics and Technology Education (SMTE). The Innovation Technologies Move Europe series of meetings[10] have come up with excellent level of student motivation and participation. Science education has taken up the format of a festival in Germany, judging from the 'science-on-stage' programmes going on in Berlin in recent years. Universities such as the National University of Singapore give a lot of importance to science outreach programmes for schools and colleges, aimed at inspiring young minds to pursue science with passion.[11] Back home in India we have the NCERT[12] and the DST[13] who have been active enthusiastically in this matter, pursuing several initiatives in an exemplary manner. The Government of India has established institutes such as HBCSE, Mumbai and IISERs at several places in the country, which are changing remarkably the perspective of science education in the country.

Need for Serious Initiatives with Innovation and Thrust

Several strategies have evolved over the years and many of these have been tried out successfully. The first and foremost point is to motivate the students to develop an interest in science. Many of them may become engineers or doctors or industrialists later, but learning basic science at the appropriate levels will enable them to perform well in all these pursuits. This requires a multilevel approach. The past one or two decades have witnessed new science books appearing and newer editions of old text books undergoing thorough modifications in content and style — good examples from physics being the books

by Halliday, Resnick and Jearl Walker, Harvey, Arthur Beiser, etc. to name a few.[14–16] They present the content in a charming way, with excellent photographs and appropriate discussions of physics in everyday life that the students can relate to very easily. Attractively designed questions and problems, internet links (to multimedia and other resources), companion volumes and CDs with simulations, etc. provide excellent value addition to such books.

There are many colleges and even Universities where students end up referring to only books written by their own professors. Of course many of them may be excellent; but the point is that students might miss out the experience of referring to the best books acclaimed globally. This is a situation which can be remedied easily in the internet era. At least, obtaining information about the global scenario and resources is no more difficult. We now have virtual classrooms being designed by world's best institutions where students can derive the benefit of almost being present in such classrooms.[17,18] The NPTEL programme funded by the Government of India[18] has been doing an excellent job and several high quality technical courses (which have gone through a thorough quality assessment and screening) have already been uploaded and are available free of cost to anyone with an internet connection in any remote corner of the world.

Practical training is something that has to be specially highlighted in the context of science education. Over the years, even the leading institutions in our country have been slowly drifting away from providing due importance and thrust to this aspect. Establishing some *standard laboratories* in the schools and colleges is not sufficient, though necessary. Specifically designated centres have to be designed and developed to conduct laboratory training programmes and inculcate the right philosophy perspective *and hands-on training* among the educators at all levels. As stated by Stowe, *common sense is the knack of seeing things as they are and doing things as they ought to be done.*[19]

A wealth of resources is available for those who look for it. Of special mention in this context is the excellent work has been done by Shri Arvind Gupta on popularising science and inspiring thousands of children through highly innovative and economic experiments.[20] Prof. Yash Pal's various excellent contributions towards inspiring students towards the wonders of science are worth special mention here.[21] Contributions by several others such as Prof. Babulal Saraf (at CDPE, University of Rajasthan)[22] and Prof. T. S. Natarajan (IIT Madras)[23] towards effective science education have made a remarkable impact. The training programmes in experimental physics by the noted physics researcher and teacher Prof. R. Srinivasan under the auspices of the Indian Academy of Sciences are relevant in this context.[24] There are several other such initiatives in the country, by dedicated people, institutions and organisations such as people's science movement (also using the media of regional languages for more effective outreach) which also should have found

mention here, but many of these are not known widely or listed readily in any single source.

The Technology of Education — Mastering the Model

The role of the teacher indeed appears to be very complex in the present scenario. Of course, the new devices are of much utility to the teacher, but there is no replacement for the central figure of teacher as such. So it is up to the teacher to get familiar with the new technologies and to make optimal use of them. The present model of a comprehensive educational system appears to be quite, complicated, but careful analysis helps one to master it and go beyond.

On the face of it, the dynamics of riding an ordinary bicycle appears to be a really complicated process; balancing the whole weight spread over the entire geometry at just two points and maneuvering it across curves, slopes and potholes. Looks almost impossible if you think logically! We all would have had a lot of struggle learning cycling. However, once we master the techniques, we seldom think about the involved processes and ride on smoothly, peacefully and happily. Teaching is also a complicated process to learn with a lot of skills to be developed through a lot of worries and struggles. Courses on education teach all these thoroughly. However, the teacher has to integrate all this into his system without bothering too much about the technicalities and specific details, just as an experienced motor driver drives smoothly without getting confused over the positions of the gears and the clutch. Young teachers often begin their career by learning to imbibe the methods of their own favorite teacher to start with; eventually they become thorough with the whole model of education. As is often described in educational circles, it is a journey from '*modeling the master*' to '*mastering the model*'.

The actual content covered in a class is just like the *tip of an iceberg*, and it is the preparation which is like the huge, deep buried part of the iceberg that keeps the tip up. It is the mastery of the subject matter and the style of presentation that leads to confidence, conviction, thoroughness, clarity and eventually, success. A teacher should be enthusiastic and sincere. Enthusiasm is contagious; it can catch attention, overcome barriers, create interest and thus make a difference. A successful teacher tries to keep the students alert, interested and inspired all the time. Each class should convey something and make a specific contribution, a value addition, towards enhancing the understanding as well as the vision of the student. Techniques such as good management of the audiovisual and electronic media, a simple and direct style, eye contact, use of proper voice modulation etc. should come naturally to an efficient the teacher.

From here to Eternity — *What Next?*

Strategies are to be evolved in areas such as student motivation. This has several facets such as attracting the brilliant student to the lure of science (irrespective of whatever profession he pursues later). This also includes

maintaining the interest generated among the students so that the interest continues to grow. Let us look at some of the possible strategies in some detail, with appropriate examples. Some of the important aspects are listed below, *without any claim at all, of being exclusive*!

- Timely and periodic revision of the content of the curriculum and incorporation of new methodologies after careful and continuous review and quality assessment.
- Teacher training with emphasis on presentation of the subject matter in an attractive manner making use of multimedia and internet resources such as simulation and animation wherever relevant.
- Focus on encouraging the students to go beyond any *local* textbook and to develop an international outlook well beyond the limited syllabus of any given University, creation of awareness of the availability of virtual classrooms of tested quality and other web resources.
- Exposure to and training on the techniques of creative thinking and problem solving in science. Apart from incorporating these in curricula, special regional centers may be set up to concentrate on this aspect, which can undertake to provide short term training to teachers and students.
- Design of mini, micro and/or full-fledged projects (at the appropriate levels) for individuals or groups of students so as to encourage their innovative and investigative skills.
- Incorporation of healthy debates among students on topics related to the tough concepts, possible misconceptions, relevance of the content learned to the world around, possible applications, social relevance, etc.
- Urgent and definitive action to bring practical training with hands-on experimentation to its rightful place in science education, encouraging (through competition, awards and prizes) innovative design of novel and preferably low-cost devices, experiments, equipment, demonstration kits, etc.
- Steps to reduce the large scale flow of brilliant minds to *greener pastures* down the gradient of societal pressures and to ensure that pursuits of science and/or science education are also made *sufficiently green!*

Though education is to be considered in a holistic manner, especially at school level, certain specific aspects need to be emphasised in the context of science education. The content and methodology of the curriculum have to provide due importance to actual experimental work in the form of laboratory work, field study and project work. Innovation is to be recognized and encouraged. The role of mathematics as the language of science and engineering and the need for a proper understanding of the logical and mathematical method to master modern science are to be highlighted. The student must be taught to distinguish between the core and the clutter, to develop a sincere, childlike curiosity and to practice the art of raising the right questions without fear, inhibition or meek acceptance. Creative thought and

problem solving skills form the cornerstones of science education.

Emphasis must be given in the content of science education to the new challenges such as harnessing solar energy and other feasible sources of alternate energy, protecting and sustaining our environment (air, soil and water, above all) and attaining one hundred percent self self-reliance in food production. Exposure to and an awareness of these really urgent topics of immediate concern to humanity at an early and proper age appear to be crucial for our very survival on this planet.

Albert Einstein has expressed his view that "Education is that which remains, if one has forgotten everything one has learned in school". It is important to develop among students, "... general ability, independent thinking and judgment and preparedness to adapt to progress and changes". According to him, the school should always have its aim that the student leaves it as a harmonious personality, not as a mere specialist.[25] Sir C. V. Raman has stated emphatically: "The essence of scientific spirit is to look behind and beyond to realize what a wonderful world it is that we live in. Everything that we see presents to us not a subject for curiosity, but a challenge to the spirit of man to try to understand something of this vast mystery that surrounds us".[26]

The treasury of experience and wisdom of original thinkers on science education provides us with an abundant measure of resources such as specific examples, tested ideas and adaptable techniques to take forward. We may have to struggle a bit, shaping bricks and polishing stones, which is an integral part of *building up a monument*. Sri Aurobindo had envisioned : *"...man may very well be a laboratory in which Nature wills to work out superman..."* .[27] It is to Mother Nature that we, the science educators, have to get enrolled as assistants. The fruits may be rewarding in the long run; but the charm and thrill of the adventure itself are worth the effort!

REFERENCES

Reference and Links to Resources:

1. A story from Chandogya Upanishad, verse 6.1.2
2. http://www.wenatcheeworld.com/news/2011/feb/19/retired-wsu-professor-accepts- agricultures-wolf/
3. http://www.vega.org.uk/video; http://amasci.com/amateur/physvids.html
4. Dan MacIsaac, The Physics Teacher, Vol. 48, October 2010 p494
5. http://www.speaksanskrit.org/forum/viewtopic.php?t=237
6. http://www.crewtonramoneshouseofmath.com/math-quotes.html
7. http://www.wisdomportal.com/Technology/TSEliot-TheRock.html
8. http://www.aapt.org/
9. http://ajp.aapt.org/
10. http://www.science-on-stage.eu
11. http://physics.nus.edu.sg/~phyoutreach/demolab.htm
12. http://www.ncert.nic.in/index.html

13. http://www.dst.gov.in/
14. *Fundamentals of Physics,* Sixth Edition by David Halliday, Robert Resnick and Jearl Walker 7th edition, Wiely, 2004
15. *Physics for Scientists and Engineers*, Raymond A. Serway, John W. Jewett Brooks Cole; 6th edition, 2003
16. Study Guide for The Physical Universe [Paperback] Konrad Krauskopf, Arthur Beiser McGraw-Hill Science/Engineering/ Math; 14th edition, 2011.
17. http://ocw.mit.edu/index.htm
18. http://nptel.iitm.ac.in/courses.php
19. http:// www. lotofquotes.com/common_sense_quotes_sayings_about _common_sense/
20. http://www.arvindguptatoys.com
21. http://en.wikipedia.org/wiki/Yash_Pal; http://www.youtube.com/ watch?v=FNDFyNJbH3M
22. http://video.google.com/videoplay?docid=611895857380356270#; Current Science, Vol. 96, No. 9, p 1270, May 2009
23. http://www.physics.iitm.ac.in/~tsn/
24. http://www.ias.ac.in/
25. From Einstein's lecture on 'Education' at Albany, USA, 1936, *quoted in Literary Reader, Functional English, CBSE Class XII*
26. From "Why the sky is blue", a radio lecture given by Sir. C. V. Raman to school children. Available free at http://www.vigyanprasar.gov.in/digilib/
27. The Essential Aurobindo: Writings of Sri Aurobindo, Robert A. Mc Dermott, *Sri Aurobindo.*