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POSITION PAPER

NATIONAL FOCUS GROUP
ON
TEACHING OF SCIENCE

विद्ययाऽमृतमश्नुते

एन सी ई आर टी
NCERT

राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

First Edition
Mach 2006 Chaitra 1928

PD 5T BS

Rs. 25.00

Printed on 80 GSM paper with NCERT watermark

Published at the Publication Department by the Secretary, National Council of Educational Research and Training, Sri Aurobindo Marg, New Delhi 110 016 and printed at Bengal Offset Works, 335, Khajoor Road, Karol Bagh, New Delhi 110 005

ISBN 81-7450-494-X

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EXECUTIVE SUMMARY

1. CRITERIA FOR AN IDEAL SCIENCE CURRICULUM

Good science education is true to the child, true to life and true to science. This simple observation leads to the following basic criteria of validity of a science curriculum:

a) *Cognitive validity* requires that the content, process, language and pedagogical practices of the curriculum are age appropriate, and within the cognitive reach of the child.

b) *Content validity* requires that the curriculum must convey significant and correct scientific content. Simplification of content, which is necessary to adapt the curriculum to the cognitive level of the learner, must not be so trivialized as to convey something basically flawed and/or meaningless.

c) *Process validity* requires that the curriculum engage the learner in acquiring the methods and processes that lead to generation and validation of scientific knowledge, and nurture the natural curiosity and creativity of the child in science. Process validity is an important criterion since it helps the student in 'learning to learn' science.

d) *Historical validity* requires that science curriculum be informed by a historical perspective, enabling the learner to appreciate how the concepts of science evolve with time. It also helps the learner to view science as a social enterprise and to understand how social factors influence the development of science.

e) *Environmental validity* requires that science be placed in the wider context of the learner's environment, local and global, enabling him/her to appreciate the issues at the interface of science, technology and society and preparing him / her with the requisite knowledge and skills to enter the world of work.

f) *Ethical validity* requires that the curriculum promote the values of honesty, objectivity, co-operation, freedom from fear and prejudice, and develop in the learner a concern for life and preservation of environment.

2. SCIENCE CURRICULUM AT DIFFERENT STAGES

Consistent with the criteria above, the objectives, content, pedagogy and assessment for different stages of the curriculum are summarized below.

At the primary stage the child should be engaged in joyfully exploring the world around and harmonizing with it. The objectives at this stage are to nurture the curiosity of the child about the world (natural environment, artifacts and people), to have the child engage in exploratory and hands on activities to acquire the basic cognitive and psychomotor skills through observation, classification, inference, etc.; to emphasize design and fabrication, estimation and measurement as a prelude to development of technological and quantitative skills of later stages; and to develop the basic language skills: speaking, reading and writing not only for science but also through science. Science and social science should be integrated as 'Environmental Studies' as at present, with health as an important component. Throughout the primary stage, there should be no formal periodic tests, no awarding of grades or marks, and no detention.

At the upper primary stage the child should be engaged in learning principles of science through familiar experiences, working with hands to design simple technological units and modules (e.g. designing and making a working model of a windmill to lift weights) and continuing to learn more on environment and health through activities and surveys. Scientific concepts are to be arrived at mainly from activities and experiments. Science content at this stage is not to be regarded as a diluted version of secondary school science. Group activity, discussions with peers and teachers, surveys, organization of data and their display through exhibitions, etc. in schools and neighbourhood are to be an important component of pedagogy. There should be continuous as well as periodic assessment (unit tests, term end tests). The system of 'direct' grades should be adopted. There should be no detention. Every child who attends eight years of school should be eligible to enter Class IX.

At the secondary stage the students should be engaged in learning science as a composite discipline, in working with hands and tools to design more advanced technological modules than at the upper primary stage, and in activities and analysis on issues surrounding environment and health. Systematic experimentation as a tool to discover/verify theoretical principles, and working on locally significant projects involving science and technology are to be important parts of the curriculum at this stage.

At the higher secondary stage science should be introduced as separate disciplines with emphasis on experiments/technology and problem solving. The current two streams, academic and vocational, being pursued as per NPE 1986 may require a fresh look in the present scenario. The students may be given an option to choose the subjects of their interest freely, though it may not be feasible to offer all the different subjects in every school. The curriculum load should be rationalized to avoid the steep gradient between secondary and higher secondary syllabus. At this stage, core topics of a discipline, taking into account recent advances, should be carefully identified and treated with appropriate rigour and depth. The tendency to superficially cover a large number of topics of the discipline should be avoided.

3. PROBLEMS AND OUTLOOK

Looking at the complex scenario of science education in India, three issues stand out unmistakably. First, science education is still far from achieving the goal of equity enshrined in our constitution. Second, science education, even at its best, develops competence but does not encourage inventiveness and creativity. Third, the overpowering examination system is basic to most, if not all, the fundamental problems of science education.

In this position paper, the Focus Group has attempted to address a range of issues related to science curriculum and problems in its implementation, but has particularly focused on the three issues mentioned above. First, we must use science curriculum as an instrument of social change to reduce the divide related to economic class, gender, caste, religion and region. We must use the textbook as one of the primary instruments for equity, since for a great majority of school going children, as also for their teachers, it is the only accessible and affordable resource for education. We must encourage alternative textbook writing in the country within the broad guidelines of the national curriculum framework. Information and Communication Technology (ICT) is also an important tool for bridging the social divides. ICT should be used in such a way that it becomes an opportunity equalizer, by providing information, communication and computing resources in remote areas.

Second, we believe that for any qualitative change from the present situation, science education in India must undergo a paradigm shift. Rote learning should be discouraged. Inquiry skills should be supported and strengthened by language, design and quantitative skills. Schools should give much greater emphasis on co-curricular and extra curricular elements aimed at stimulating investigative ability, inventiveness and creativity, even if these elements are not part of the external examination system. We strongly recommend a massive expansion of non-formal channels (for example, a truly large scale SCIENCE & TECHNOLOGY FAIR with feeder fairs at cluster/ district/state levels) to encourage schools and teachers to implement this paradigm shift.

Third, we recommend nothing short of declaring examination reform as a National Mission (like other critical missions of the country), supported by funding and high quality human resources that such a mission demands. The mission should bring scientists, technologists, educationists and teachers on a common platform and launch new ways of testing students which would reduce the high level of examination related stress, curb the maddening multiplicity of entrance examinations, and research on ways of testing multiple abilities other than formal scholastic competence.

These reforms, however, fundamentally need the over arching reform of teacher empowerment. No reform, however well motivated and well-planned, can succeed unless a majority of teachers feel empowered to put it in practice. With active teacher participation, the reforms suggested above could have a cascading effect on all stages of science teaching in our schools.

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CONTENTS

1. INTRODUCTION

What should science education aim at? Our engagement with this question takes us first to the more general question: what is the basic goal of education? To be brief, we can do no better than quote Gandhi: "True education is that which draws out and stimulates the spiritual, intellectual and physical faculties of the children". Implicit in this aim is the belief (that we share) that education has the potential to transform individuals and societies. What then are we looking for, as we particularize our thoughts on science education? Clearly, any discussion of the aims of science education presupposes a view of science, its methods, scope and limitations. Before we dwell on science education, we must, therefore, briefly comment on the nature of science.

1.1 Nature of Science

Humans have always been curious about the world around them. The inquiring and imaginative human mind has responded to the wonder and awe of nature in different ways. One kind of response from the earliest times has been to observe the physical and biological environment carefully, look for any meaningful patterns and relations, make and use new tools to interact with nature, and build conceptual models to understand the world. This human endeavour is science.

Science is a dynamic, expanding body of knowledge covering ever new domains of experience. How is this knowledge generated? What is the so-called scientific method? As with many complex things in life, the scientific method is perhaps more easily discerned than defined. But broadly speaking, it involves several interconnected steps: observation, looking for regularities and patterns, making hypotheses, devising qualitative or mathematical models, deducing their consequences; verification or falsification of theories through observations and controlled experiments, and thus arriving at the principles, theories and laws governing the physical world. There is no strict order in these various steps. Sometimes, a theory may suggest a new experiment; at other times an experiment may suggest a new theoretical model. Speculation and conjecture also have a place in science, but ultimately, a scientific theory, to be acceptable, must be verified by relevant observations and/or experiments. The laws of science are never viewed as fixed eternal truths. Even the most established and universal laws of science are always regarded as provisional, subject to modification in the light of new observations, experiments and analysis.

The methodology of science and its demarcation from other fields continue to be a matter of philosophical debate. Its professed value neutrality and objectivity have been subject to critical sociological analyses. Moreover, while science is at its best in understanding simple linear systems of nature, its predictive or explanatory power is limited when it comes to dealing with non-linear complex systems of nature. Yet, with all its limitations and failings, science is unquestionably the most reliable and powerful knowledge system about the physical world known to humans.

But science is ultimately a social endeavour. Science is knowledge and knowledge is power. With power can come wisdom and liberation. Or, as sometimes happens unfortunately, power can breed arrogance and tyranny. Science has the potential to be beneficial or harmful, emancipative or oppressive. History, particularly of the twentieth century, is full of examples of this dual role of science.

How do we ensure that science plays an emancipative role in the world? The key to this lies in a consensual approach to issues threatening human survival today. This is possible only through information, transparency and a tolerance for multiple viewpoints. In a progressive forward-looking society, science can play a truly liberating role, helping people out of the vicious circle of poverty, ignorance and superstition. In a democratic political framework, the possible aberrations and misuse of science can be checked by the people themselves. Science, tempered with wisdom, is the surest and the only way to human welfare. This conviction provides the basic rationale for science education.

1.2 Science and Technology

Technology is often equated to applied science and its domain is generally thought to include mechanical, electrical, optical and electronic devices and instruments, the household and commercial gadgets, applications of chemical, biological, nuclear sciences and computer and telecommunication technologies. These various sub-domains of technology are, of course, interrelated. Viewing technology, especially modern technology, as applied science is, therefore, not wrong. Much of technology that we see around is indeed informed by the basic principles of science. However, technology as a discipline has its own autonomy and should not be regarded as a mere extension of science. After all, technology was part of ancient human civilizations and even prehistory, but science in its modern sense is relatively recent - only about four centuries old. In fact there is much local technological knowledge existing around the world that is in danger of extinction due to the sweeping dominance of modern technology.

Basically science is an open-ended exploration; its end results are not fixed in advance. Technology, on the other hand, is also an exploration but usually with a definite goal in mind. Of course, technology is as much a creative process as science, since there are, in principle, infinite ways to reach the given goal. Creativity consists in new ways of designing, planning and charting out the map to the final end, as also in innovative applications of the known principles of science. Technological solutions are guided as much by design, aesthetic, economic and other practical considerations as by scientific principles. Science is universal; technology is goal oriented and often local specific.

Our very definition of progress is linked with advances in science and technology. These advances have led to unimagined new fields of work and transformed, often beyond recognition, traditional fields like agriculture, manufacturing, construction, transport and entertainment. People today are faced with an increasingly fast-changing world where the most important skills are flexibility in adapting to new demands and creativity in taking advantage of new opportunities. These imperatives have to be kept in mind in shaping science education.

1.3 Science Education: Types of Validity

Our brief discussion on the nature of science and technology brings us now to the main question: what is our vision of true science education? There are three factors involved here: the learner (child), the environment - physical, biological and social (life) in which the learner is embedded, and the object of learning (science). We can regard good science education as one that is true to the child, true to life and true to science. This observation naturally leads to some basic criteria for validating a science curriculum, as suggested below:

a) *Cognitive validity* requires that the content, process, language and pedagogical practices of the curriculum are age appropriate, and within the cognitive reach of the child.

b) *Content validity* requires that the curriculum must convey significant and scientifically correct content. Simplification of content, which is often necessary to adapt the curriculum to the cognitive level of the learner, must not be so trivialized as to convey something basically flawed and/or meaningless.

c) *Process validity* requires that the curriculum engage the learner in acquiring the methods and processes that lead to generation and validation of scientific knowledge, and nurture the natural curiosity and creativity of the child. Process validity is an important criterion since it helps in 'learning to learn' science.

d) *Historical validity* requires that science curriculum be informed by a historical perspective, enabling the learner to appreciate how the concepts of science evolve with time. It also helps the learner to view science as a social enterprise and to understand how social factors influence the development of science.

e) *Environmental validity* requires that science be placed in the wider context of the learner's environment, local and global, enabling him/her to appreciate the issues at the interface of science, technology and society, and preparing him / her with the requisite knowledge and skills to enter the world of work.

f) *Ethical validity* requires that the curriculum promote the values of honesty, objectivity, co-operation, freedom from fear and prejudice, and develop in the learner a concern for life and preservation of environment.

2. RESEARCH IN SCIENCE EDUCATION

About 40 years ago science education came to be recognized around the world as an independent field of research. The concerns of this research are distinct from the concerns of science and those of general education. Its methods and techniques were initially borrowed from the sciences but new methods are being developed suited to the research questions[1].

Motivation for this research comes from the need to improve the practice of science education. We begin by asking, which methods of teaching work better than others? Studies in the 1970s typically compared experimental classrooms with controls. New teaching aids were tried out, lecture methods were compared with activity-based teaching, and so on. These studies gave useful results in particular contexts but it was hard to replicate them. Conditions in classrooms are varied; teacher and student characteristics too vary widely. Teaching and learning are complex, context-dependent processes and one needs to first describe this complexity in order to understand it, before eventually aiming to control it([2]; [3]).

The early studies led to many new lines of enquiry. One line looked at the social context of teaching and learning and of the interpersonal dynamics occurring in science lessons. This kind of research has drawn on methods from sociology, linguistics and anthropology. New tools for classroom observation have reached a considerable level of sophistication ([4]; [5]). In general one knows that a supportive relationship among students and teachers, student participation in setting goals and making decisions, clear expectations and responsibilities, and opportunities for collaboration, are some factors which lead to better student outcomes [6]

Asking questions

"Air is everywhere" is a statement that every school child learns. Students may know that the earth's atmosphere consists of several gases, or that there is no air on the moon. We might be happy that they know some science. But consider this conversation that happened in a 4th standard classroom.

Teacher: Is there air in this glass?
Students (in chorus): Yes!

This teacher was not satisfied with the usual general statement "air is everywhere. She asked the students to apply the idea in a simple situation, and found, unexpectedly, that they had formed some "alternative conceptions".

Teacher: Now I turn the glass upside down. Is there still air in it?
(Some students say "yes", others say "no", still others are undecided.)
Student 1: The air came out of the glass!
Student 2: There was no air in the glass. In standard 2 the teacher put an empty glass over a burning candle and the candle went out!

The students had performed an activity, which remained vivid two years later, but some of them at least had taken away an incorrect conclusion from it.
After some explanations the teacher went on to further question the students. Is there air in this closed cupboard? Is there air in the soil? In water? Inside our body? Inside our bones? Each of these questions brought up new ideas and presented an opportunity to clear some misunderstandings. This lesson was also a message to the class: do not accept statements uncritically. Ask questions. You may not find all the answers but you will learn more.

Experiments are the hallmark of science, and for science learning, they are essential. In India there has been considerable work on developing simple low-cost experiments for use in schools. Research in science education has studied how students' learning follows from doing experiments or watching demonstrations. This research was stimulated as a consequence of evaluations carried out of the "inquiry" or "discovery approach" curricula that were implemented in UK, USA and in many developing countries too in the 1960s and 1970s.

The inquiry curricula are based on an inductivist conception, in which discoveries follow directly from unbiased observations ([7], [8]). Several problems - logical, psychological and logistical - were encountered in putting the inquiry approaches to work ([9], [10], [11]). One problem was in connecting observation with inference[12]. Observations in science are usually motivated by a theory or a hypothesis. In a classroom, however, experiments are motivated by the teacher or the textbook; the students either watch or follow instructions; they are told which particular observation to focus on, and the inference is also told to them. Let us take an example. A candle is lighted and then covered with a glass. To the question, "What does this experiment show?", the common answer is, "This experiment shows that air contains oxygen" a clearly unwarranted conclusion, but one that is often accepted in classrooms.

Clearly, for experiment based science learning to be effective, there must be space and time for teachers and students to plan experiments, discuss ideas, and critically record and analyze observations. A good pedagogy must essentially be a judicious mix of approaches, with the inquiry approach being one of them.

Science learning needs the effective use of language. Psychologists know of the intimate relation between language and thought. Language is more than a way of labelling things around us; it is a tool that helps us conceptualize. Language adds meaning to, and aids in interpreting our experiences. Research on the role of language in science learning has led to better understanding of metaphor and analogy, and of how meaning is drawn from science activities. ([13], [14]).

Learning science in a second language adds a considerable burden, particularly at the primary school level[15]. Another problem is the often unnecessarily complicated language of science textbooks. Simplifying the language of textbooks has been found to improve teacher-pupil interaction in classrooms[16]

A major finding of research has been that students hold conceptions about natural phenomena, which are different from what they are told in the textbook or what they are taught by the teacher. These are not simply wrong ideas but they follow their own logic and are often based on experience[17]. Across the world researchers find students believing that the material which is produced in growing plants comes from the soil: that air plays only a minor part in this process. Students imagine that matter is destroyed during burning; they think that constant motion requires a force to maintain it and that electric current is used up in lighting a bulb[18]. Such erroneous views are widespread and also highly resistant to change, even through carefully constructed teaching programmes.

Since science education is dependent on context, it is important for research to be carried out in our own environment. Studies done in India have found that tribal students' knowledge about the living world is rich and largely reflects their environment and lifestyle. In comparison, urban students' ideas about living things are shaped by knowledge gained through books and stories[19]. Conceptions about health and disease too have been found to be rooted in culture and environment[20].

Science education research has drawn from, and also contributed to, the interdisciplinary field of cognitive science[21]. Cognitive science in turn has drawn on models and methods from psychology and artificial intelligence (AI). The classical AI approach sees knowledge as stored in the form of propositions which can be represented as networks of nodes and links: i.e. concepts, and the relationships between them. This approach looks to characterize the knowledge frameworks of experts and novices and study the difference between them.

Experts perform better than novices in memory tests as well as in problem solving, but this superiority is limited to their own domain of expertise ([22], [23]). Expertise relies on methods that work very well in that domain, and not so much on general skills, which transfer between domains. Experts see and represent a physics problem at a deeper, more principled, level than do novices – e.g. they may notice that the conservation of energy is relevant in a particular situation. Novices tend to represent the same problem at a superficial level - say, as a situation involving springs or pulleys. Experts tend to have more, and more meaningful linkages between their concepts.

In the knowledge representation approach "learning", i.e. the transition from novice to expert performance, is seen as a re-structuring of students' frameworks of concepts and propositions. To test for such learning, new methods of assessment have been developed like, concept maps and semantic networks[24]. Such qualitative methods of assessment are particularly useful in obtaining feedback during the course of teaching.

In recent years assessment and evaluation have come to play a significant role within the educational system as a whole. In an atmosphere of international competition governments are seeking to build educational systems, which are responsive to national priorities. Thus large-scale systemic testing has become an important requirement for educational policy-making[25].

3. Sceince Curriculum at the National Level: A Brief History

Compulsory teaching of science, as a part of general education up to Class VII or VIII, had been in practice in most of the states and UTs before the introduction of a uniform pattern of school education in 1975. During this period the subject was usually taught as general science in most of the states. However, at the secondary stage science was an optional subject, which was offered either as a combination of physical science and biology or as physics, chemistry and biology. The syllabus of science and textbooks were prescribed by the respective state agencies. The content and process of science teaching in schools, therefore, varied from one state to another.

The general objectives of science teaching identified for Classes I–VIII during the 1960s have been basic to the evolution of science education in the country, particularly at the elementary stage. The major objectives identified were:

- to acquire knowledge of biological, physical and material environments including forces of nature and simple natural phenomena, and
- to develop scientific attitudes such as objective outlook, spirit of enquiry, truthfulness and integrity, inventiveness, accuracy and precision, avoiding hasty conclusions on insufficient data, respect for the opinions of others.

The instructional material developed by the NCERT under UNICEF aided project, during 1967-70 was based on an activity-based approach to the teaching of science at the primary stage. The package of instructional material comprising syllabus, textbooks (titled "*Science is Doing*"), handbook of activities, teachers' guides, science kit and audio-visual material were developed through a process of trial in a limited number of schools. The instructional package developed for the middle schools, Classes VI to VIII, too comprised similar components and was also developed through field trials.

The Education Commission chaired by Prof. D.S. Kothari has been an important landmark for its depth and expanse of vision of education in India[26]. This led to the introduction of the 10+2+3 pattern of education in 1975. A National Curriculum Committee gave recommendations and guidelines for the new pattern through a policy document titled '*The Curriculum for the Ten-Year School - A Framework*'[27]. Some of the main recommendations contained in the '*Framework*' that had a direct implication on the teaching of science, its syllabi and textbooks were:

- all subjects including science and mathematics were to be compulsory for all students up to Class X, as a part of general education,
- at the primary stage, science and social sciences were to be taught as a single subject: '*Environmental Studies*',
- an integrated approach was to be followed for the teaching of science at the upper primary stage as opposed to disciplinary approach that was then in vogue, and
- science was to be considered as one composite subject at the upper primary and secondary stages.

For Classes I and II there was to be only a 'Teachers' Guide' and no textbooks, while separate textbooks in science and social studies were prepared for Classes III to V. A set of common themes was selected for teaching of '*Environmental Studies*' *(science)* in Classes I to V to follow a spiral approach for introducing the concepts in a graded manner.

The major guiding factors for the nature and scope of teaching science as an integrated course at the upper primary stage were that:

- science is one; different disciplines of science are only tentative compartmentalization of the subject to facilitate the study of its different aspects; the integrated curriculum should highlight this unified nature of science,
- curriculum should attempt to link teaching of scientific principles with daily life experiences of the learners,
- science curriculum should stress more on the processes of science than the product,
- teaching of science should lead to development of certain values,
- curriculum should provide enough opportunities to learners to attain some basic levels of scientific literacy, and
- curriculum should provide ample opportunities to the teachers to try and apply a variety of methods of teaching to suit the needs of learners of different backgrounds.

The approach adopted for the upper primary stage was extended to the secondary stage although a disciplinary approach was recommended for the latter. However, a Review Committee under the chairmanship of Sri Ishwarbhai Patel in 1977 recommended that science at the secondary stage should be offered through two equivalent alternate courses. The 'Course B' was to be a composite course in science to be taught through a single textbook. For 'Course A', it recommended a discipline orientated approach in which physics, chemistry and biology were to be taught as separate subjects. The system of alternate courses was discontinued from the academic session 1984-1985 mainly because of the perceived superiority of one course over the other.

The '*Framework*' of 1975 provided general guidelines and instructional objectives only up to the secondary stage. The responsibility of identifying aims and objectives of science teaching and the development of the syllabi and textbooks for different disciplines at the senior secondary stage was given to the curriculum developers.

The next important development was the National Policy on Education (NPE - 1986), which subsequently led to the development of the document '*National Curriculum for Elementary and Secondary Education - A Frame-Work*' [28] (NCF - 88). As before, it recommended teaching of science as a part of '*Environmental Studies*' at the primary stage. It also gave specific guidelines for the two integral components of '*Environmental Studies*', namely, science and social studies. The guidelines provided by the NCF-88 were further elaborated in a brochure titled '*Science Education for First Ten Years of Schooling - Guidelines for Upper Primary and Secondary Classes*'. The seven dimensions of science education identified in this document in fact correspond to the different criteria of validities already mentioned. The teaching of science at the secondary stage was conceived for the first time as a single subject rather than three separate disciplines as had been the practice in the past. This has since been one of the major distinguishing features of the science curriculum for this stage.

The main features of the *National Curriculum Framework for School Education – 2000*[29] pertaining to science education have been:

- teaching of environmental studies as a single subject of study at the primary stage instead of environmental studies (science) and environmental studies (social science),
- teaching of '*Science and Technology*' in place of '*Science*' at the upper primary and secondary stages, so as to familiarize the learner with various dimensions of scientific and technological literacy, and
- to continue the practice of teaching science at the higher secondary stage as separate disciplines: physics, chemistry and biology.

Thus, science curriculum in India has undergone several changes, both in approach and content, during the last forty years or so. At the primary stage, teaching of science as a single subject was first replaced by *Environmental Studies (science)* and subsequently by an integrated course on *Environmental Studies*. At the upper primary stage, the disciplinary approach was replaced first by an integrated approach to science as a single subject, and finally by an approach integrating science and technology. The changes at the secondary stage too have had a similar pattern, albeit with some phase lag.

The syllabi and textbook development programmes at the state/UT level also followed curriculum renewal exercises at the national level. The instructional materials developed by the NCERT at the national level were adopted or adapted by some of the states/UTs while others evolved their own mechanisms. In some states science at the secondary stage is taught as a combination of physical science and biological or life science while in some others as physics, chemistry and biology or life science. However, compulsory teaching of science and environmental orientation to science teaching up to secondary stage has been a common feature in science curricula of all the states/UTs.

To summarize, major curriculum renewal programmes in science in India have evolved in keeping with contemporary global trends in science education and the changing societal needs. Yet this has not reflected in the actual quality of science teaching in schools. This has been mainly due to dilution of inputs at every stage of implementation, an issue that we address throughout this paper.

4. LESSONS FROM INNOVATIVE PROGRAMMES AND INTERVENTONS

The gap perceived between recommendations of various commissions and committees and actual practice motivated several individuals and voluntary groups to take up innovative programmes on science teaching in schools.

Many of these groups had practicing scientists and academics working in collaboration with teachers and teacher associations to develop activity-based science curricula in schools. Their efforts were supported by Government institutions like the NCERT and the UGC. One of the early lessons of these efforts was that reform in evaluation had to be part of any initiative for change. Going further, a reform of science teaching should aim to comprehensively address all factors that affect the teaching-learning process.

The programmes aimed at addressing three main problems. These are: first, the sheer weight of concepts and facts taught; second, the mismatch between cognitive development of the child and the concepts taught; and third, the imbalance in teaching methods used in the classroom - there is too much emphasis on drill and rote learning and too little emphasis on observation, design, analysis, argumentation and process skills in general. A major roadblock to reforms, however, has been the public concern about the attainment levels of students in external examinations.

Several innovative programmes have been operational since the 1980s, by the Government as well as by external agencies, for reforming school education including science teaching. An example of a macro-level intervention is the *District Primary Education Programme* (DPEP) which has since been extended to the *Sarva Shiksha Abhiyan* (SSA). These interventions have been sustained over several years in identified regions of the country. In most of these, science teaching has formed part of a general thrust towards universalization of elementary education. A somewhat different approach to innovation has been taken by the Homi Bhabha Centre for Science Education (HBCSE) of the Tata Institute of Fundamental Research (TIFR), where a series of micro-level interventions as well as science popularization and talent nurture efforts have been supported by research and development of materials and methods.

The *Hoshangabad Science Teaching Programme* (HSTP) is an example of a micro level intervention at the middle school stage, which was adopted by a state Government (Madhya Pradesh, in 1978) and expanded to the macro level to run in over a thousand schools. Some of its structural innovations (e.g. cluster resource centres) were subsequently adopted by other large scale programmes. Its 30-year history shows the importance of a comprehensive curricular package comprising textbooks, kits, teacher training, school follow-up, feedback meetings and other ways of providing support to teachers, and, perhaps most importantly, examinations. A fall-out of the HSTP was the establishment of *Eklavya*, an NGO with a mandate of innovation in school education, whose primary programme 'Prashika' has provided inputs to other curriculum development efforts at the primary stage.

DPEP was a primary school programme initiated by the Central Govt. with multilateral funding but managed by the respective State Govts. In 1994 it covered 42 districts in seven states: Assam, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra and Tamil Nadu[30] DPEP's scope was gradually expanded to more than 280 districts and its successor SSA now aims to cover all 593 districts of the country[31]. Lok Jumbish (LJ) was a state government programme of Rajasthan covering elementary schooling up to Class VIII, but its management was vested in an autonomous body (Lok Jumbish Parishad) set up for the purpose. The LJ programme has since been subsumed under SSA.

All of these programmes fostered an activity-based, learner-oriented pedagogy in which the child was encouraged to build on her own experiences and learn from her environment. Below we note some lessons derived from local-level assessments of these large-scale field interventions:

- Scale and intensity generate their own dynamics, which create a climate for change. Any single innovation has ripple effects that induce changes across the board. Changing the classroom methodology impacts on textbook writing, teacher training, academic back-up systems and so on. So innovations need to be viewed in a holistic - not piecemeal - manner and implemented in a mission mode.
- The mission mode calls for identifying a 'cause' with which stakeholders can identify, both emotionally and intellectually. The means include 'science caravans' and 'science melas' serving to expose people to the idea of learning science through experiments, cultural programmes, public rallies and meetings with parents and teachers. Interest in the innovation is thus generated among parents and other stakeholders.
- Teacher motivation is a crucial aspect. Motivating means reorienting teachers to the new methodology, enhancing their confidence levels, enabling them to participate at all stages of the innovation and giving them a sense of self worth and status. This is done through teachers meetings, teacher trainings and school visits.
- Broadly, two types of models are possible for in-service teacher training. One is the cascade model - training master trainers who in turn train teachers. The other model entails large-scale centralized trainings. A key aspect of training is to change the mindset among the teachers that they need not know everything and that they would be more effective facilitating learning among children than trying to be the fount of all knowledge.
- An equally important task is to get teachers to think independently, enhance their content knowledge and adopt a rigorous approach in their teaching[32]. Achieving this end, particularly through a cascade model of training, is difficult. Yet the group dynamics in trainings is such that it creates a climate for change, stimulates peer group interaction and accelerates learning.
- These programmes evolved an organizational set-up to establish interconnections at the field level. The most prevalent model included a Block Resource Centre (BRC) at the block level and a Cluster Resource Centre (CRC) at the level of a cluster of schools. Another model consisted of a Sangam Kendra, comprising a high school, its feeder middle schools and their feeder primary schools. They enabled decentralization and provided a framework for organizing regular meetings and in-service training of teachers; follow-up visits to schools, conducting examinations, etc. It was an academic support system that permitted greater peer group interaction and exchange of ideas in the teacher community.
- Another effective mode of change comes through out-of-school creative activities including science melas, science clubs and libraries. Field-level experience shows that science teaching in schools cannot be improved significantly without such informal activities to back it up.
- Generally all the programmes succeeded in making the classrooms more participative.

> Teaching was no longer a one-way street. Teachers were less authoritarian, gave children greater freedom and facilitated rather than dictated learning. Children asked more questions and participated in group activities.

In summary, these interventions have shown that transforming the existing system of education is possible if upscaling of these innovative models is properly planned and executed. It would basically involve going from an exclusive delivery model to one where the community can demand and enable change. Decentralization would contribute to local relevance of curricula. Centralized approaches, however, still have their role in suggesting directions for change. These suggestions now can be based on inputs from research and development programmes.

5. AIMS OF SCIENCE EDUCATION AND ORGANIZATION OF CURRICULUM AT DIFFERENT STAGES

5.1 Aims of Science Education

The general aims of science education follow directly from the six criteria of validity: cognitive, content, process, historical, environmental and ethical. (See 'Science Education: Types of Validity'.) To summarize, science education should enable the learner to

- know the facts and principles of science and its applications, consistent with the stage of cognitive development,
- acquire the skills and understand the methods and processes that lead to generation and validation of scientific knowledge,
- develop a historical and developmental perspective of science and to enable her to view science as a social enterprise,
- relate to the environment (natural environment, artifacts and people), local as well as global, and appreciate the issues at the interface of science, technology and society,
- acquire the requisite theoretical knowledge and practical technological skills to enter the world of work,
- nurture the natural curiosity, aesthetic sense and creativity in science and technology,
- imbibe the values of honesty, integrity, cooperation, concern for life and preservation of environment, and
- cultivate 'scientific temper'-objectivity, critical thinking and freedom from fear and prejudice.

5.2 Curriculum at Different Stages: Objectives, Content, Pedagogy and Assessment

Within the frame of reference of general aims, the objectives, content, pedagogy and assessment would differ across different stages. Research in science education, experiences of curricula at national and state level over the past several decades and different interventional programmes of voluntary groups have shed considerable light on the scope and gradation of the school curriculum. While deciding on gradation of science curriculum, it must be borne in mind that a majority of students learning science as a compulsory subject up to Class X are not going to train as professional scientists or technologists in their later careers; yet they need to become 'scientifically literate', since several of the social, political and ethical issues posed by contemporary society increasingly revolve around science and technology. Consequently, the science curriculum up to Class X should be oriented more towards developing awareness among the learners about the interface of science, technology and society, sensitizing them, especially to the issues of environment and health, and enabling them to acquire practical knowledge and skills to enter the world of work. It should stress not only the content of science, but, more importantly, the process skills of science, that is, the methods and techniques of learning science. This is necessary since the process skills are more enduring and enable the learner to cope with the ever changing and expanding field of science and technology. Of course, this does not mean that the content can be ignored. Facts, principles, theories and their applications to understand various phenomena are at the core of science and the science curriculum must obviously engage the learner with them appropriately. However, science up to Class X should be learnt as a composite subject and not as separate disciplines such as physics, chemistry and biology. At the higher secondary stage, however, the requirements of different disciplines of science become important and they need to be learnt in depth and with rigour appropriate at that stage.

5.2.1 Primary Stage (Classes I to V)

Primary science education has to be a phase of joyful learning for the child with ample opportunities for exploration of the environment, to interact with it and to talk about it.

The main objectives at this stage are to arouse curiosity about the world (natural environment, artifacts and people) and have the child engage in exploratory and hands-on activities that lead to the development of basic cognitive and psychomotor skills through language, observation, recording, differentiation, classification, inference, drawing, illustrations, design and fabrication, estimation and measurement. The curriculum should also help the child internalize the values of cleanliness, honesty, co-operation, concern for life and environment. At the primary stage, children are actively developing their language skills – speaking, reading and writing, which is important to articulate their thoughts and develop the framework for observing the world. This is the stage, therefore, to emphasize language development through and for science learning. Learning through local language / mother tongue is the most natural; but even while teaching in the local language care should be taken not to adopt a 'purist' approach, and not to load the child with terms and words that mean nothing to the child.

The criteria for identifying the content at the primary stage are relevance, meaningfulness and interest to the child. The content should provide opportunities to deal with the real and concrete world of the children, rather than a formal abstract world. The present practice of introducing ideas and concepts pertaining to science and social science as *Environmental Studies* should be continued and further strengthened, with health education as an important component. It is, therefore, essential for the curriculum, syllabus and text book developers of both the 'sciences' and 'social studies' groups to work together.

The pedagogy should essentially be based on activities in and out of classroom, as well as other methods such as stories, poems, plays and other kinds of group activities. Primary school students particularly in rural areas have rich interactive experience of the natural world and the curriculum should nurture and sustain this interest. Activities should allow free exploration, seeing patterns, making comparisons and understanding the web of relationships. This would enable the child to appreciate the similarities and the differences in nature, in the sounds, the colours, the sights, the shapes, etc. Concern for environment and inculcation of related values can be promoted through activities (planting of seeds, protecting trees, not wasting water, etc.) and practices relating to health, hygiene and social interactions are best taught by example rather than through recitations from a text book. The atmosphere in the classroom should not stress the child to perform, but allow learning to take place at individual pace and permit free interaction among children and the teacher.

The present practice of not prescribing a textbook for environmental studies for Classes I and II should be continued. The teaching-learning process should essentially be unstructured i.e. it should not follow a predetermined sequence of content or activities. The teacher should be free to devise his/her teaching learning sequence to accomplish the overall objectives of environmental studies for this stage. There should be no formal assessment. The teachers' own observations of the child should form the assessment that is shared with the child's guardians. The progress card of the child should indicate only general observations on interests, abilities, skills, status of health and other aspects of the child. For Classes III to V, the teaching-learning process may be more structured, but should still continue to be based on continuous assessment. The assessment should aim at gaining greater insight into various aspects of the child's learning: language comprehension, reading ability, articulation, ability to work with hands and in groups, skills of observation, classification, drawing, and the other skills which constitute learning at this stage.

Throughout the primary stage, there should be no formal periodic tests, no awarding of grades or marks, no pass or fail criterion and, therefore, no detention. Merit ordering of students at the primary stage should be dispensed with entirely. The class teacher should be empowered to carry out continuous assessment as per well laid out guidelines.

5.2.2 Upper Primary Stage (Classes VI to VIII)

At the upper primary stage the children are getting their first exposure to 'science'; this then is the time to bring home the right perspective of what it means to 'do science'. Science education at this stage should provide a gradual transition from environmental studies of the primary stage to elements of science and technology.

Scientific concepts to be taught at this stage should be chosen so as to make sense of everyday experiences. Though most concepts should be arrived at from activities/experiments, a rigidly inductive approach is not necessary. It is important to ensure that a majority of activities and experiments are inexpensive and use readily available materials, so that this core component of science curriculum can be implemented in all schools including those with inadequate infrastructure. Experience has shown that experiment-based science teaching is possible and viable under diverse conditions and with a very reasonable demand on resources.

Science content at the upper primary stage should not be governed by disciplinary approach and is not to be regarded as a diluted version of secondary stage science curriculum. Technology component of science curriculum could include design and fabrication of simple models, practical knowledge about common mechanical and electrical devices and local specific technologies. It is necessary to recognize that there is a lot of diversity in the nature of technology that children from different areas of the country deal with. These differences in exposure and interest should be addressed through specific contextualized projects.

Apart from simple experiments and hands on experiences, an important pedagogic practice at this stage is to engage the students (in groups) in meaningful investigations -particularly of the problems they perceive to be significant and important. This may be done through discussions in the class with the teacher, peer interactions, gathering information from newspapers, talking to knowledgeable persons in the neighbourhood, collecting data from easily available sources and carrying out simple investigations in the design of which the students have a major role to play. Organizing information and displaying it in the classroom, in the school or in the neighbourhood, or

What Biology do students know?

"These students don't understand science ... they come from a deprived background!" We frequently hear such opinions expressed about children from rural or tribal backgrounds. Yet consider what these children know from everyday experience:

Janabai lives in a small hamlet in the Sahyadri hills. She helps her parents in their seasonal work of rice and *tuar* farming. She sometimes accompanies her brother in taking the goats to graze in the bush. She has helped bring up her younger sister. Nowadays she walks 8 km every day to attend the nearest secondary school. Janabai maintains intimate links with her natural environment. She has used different plants as sources of food, medicines, fuel wood, dyes and building materials; she has observed parts of different plants used for household purpose, in religious rituals and in celebrating festivals. She recognizes minute differences between trees, and notices seasonal changes based on shape, size, distribution of leaves and flowers, smells and textures. She can identify about a hundred different types of plants around her, many times more than her biology teacher can - the same teacher who believes Janabai is a poor student.

Can we help Janabai translate her rich understanding into formal concepts of biology? Can we convince her that school biology is not about some abstract world coded in long texts and difficult language: it is about the farm she works on, the animals she knows and takes care of, the woods that she walks through every day? Only then will Janabai truly learn science.

through skits and plays are an important part of the pedagogy to ensure larger participation and sharing of learning outcomes. Biographical narratives of scientists and inventors are a useful practice to inspire students at this stage.

The emphasis on the process skills of science should continue through the upper primary stage to enable children learn how to learn for themselves so that they could carry on learning to even beyond school.

There should be continuous and periodic assessment (unit tests, term end tests), with much less weightage to the annual examination. At the upper primary stage, assessment should be completely internal with no external Board examination. Direct grading system should be adopted. The report card should show these grades for various components of assessment, but there should be no pass/fail grade and no detention. Every child who attends eight years of school should be eligible to enter Class IX. Merit ordering of students should be strongly discouraged.

The periodic tests should have both a written and an experimental component, with the practising teachers setting the question papers. Introducing open book examination is one way to ensure moving away from mere information seeking questions in examinations. The examinations should assess the child's practical and problem solving skills, ability to analyze data; application of knowledge learnt; understanding of concepts; understanding, reading and making graphical representations; and solving simple numerical exercises.

During the upper primary stage, children enter adolescence and are likely to try to be free of the confines of home and parental care and assert their independence, sometimes by experimenting with smoking, drugs and sex. We need to be sensitive to their explorations of their self and body, as well as the outside world. While science textbooks provide factual information on the human body, reproduction, safe sex, drugs, smoking, etc., this is not enough. The classroom does not provide enough scope for wider and participative discussions on sex and related matters. The school should set aside some time every week for interactions in which students can share and seek information, discuss and clarify their doubts, with teachers and, if possible, counsellors. Such a time slot should be available to students throughout the later stages of schooling also.

5.2.3 Secondary Stage (Classes IX and X)

At the secondary stage, the beginning made at the earlier stage to introduce science as a discipline is to be further strengthened without emphasis on formal rigour. Concepts, principles and laws of science may now appear in the curriculum appropriately but stress should be on comprehension and not on mere formal definitions. The organization of science content around different themes as being practiced seems appropriate at the secondary stage, but the curricular load needs to be substantially reduced to make room for the additional elements of design and technology, and other co-curricular and extra curricular activities.

At the secondary school stage, concepts that are beyond direct experience may come to occupy an important place in the science curriculum. Since not all phenomena are directly observable, science also relies on inference and interpretation. For example, we use inference to establish the existence and properties of atoms, or the mechanism of evolution. By this time, however, students should have developed the critical ability to evaluate the epistemological status of facts that they encounter in science.

Experimentation, often involving quantitative measurement, as a tool to discover/verify theoretical principles should be an important part of the curriculum at this stage. The technological modules introduced at this stage should be more advanced than at the upper primary stage. The modules should involve design, implementation using the school workshop, if possible, and testing the efficacy of the modules by qualitative and quantitative parameters. Experiments (and, as far as feasible, the technological modules) should be part of the content of the secondary stage textbook, to avoid their marginalization or neglect. However, this part of the textbook should be subject to internal assessment only. The theoretical test at this stage including that for the Class X external Board examination should have some questions based on the experiments/technological modules included in the textbook.

Participation in co-curricular activities must be regarded as equally important at this stage. These may involve taking up projects (in consultation with teachers) that bear on local issues and involve the problem-solving approach using science and technology.

The various components of the science curriculum indicated above should be integrated imaginatively. The entire upper primary and secondary school curriculum should have horizontal integration and vertical continuity.

5.2.4 Higher Secondary Stage (Class XI and XII)

At the higher secondary stage, the present policy of two streams, academic and vocational, being pursued as per the National Policy of Education 1986 may be reviewed, so that students have an option to choose the subjects of their interest freely, though all the different subjects may not be offered by every school/ junior college.

The curriculum at this stage should be disciplinary in its approach, with appropriate rigour and depth. Care should be taken not to make the syllabus heavy. The curriculum load should be rationalized to avoid the steep gradient between secondary and higher secondary syllabus, but this should not amount to making higher secondary syllabus only a slightly upgraded variant of secondary stage science. There should be strong emphasis on experiments, technology, and investigative projects.

Defining the appropriate advanced content for the higher secondary level is a matter of technical detail. What is clear, however, is what it should not be. The content should not be information laden, and not aim to widely cover all aspects of the subject. Considering the vast breadth of knowledge in any subject, the exigencies of time and the student's capacity, some delimitation, or rather, identification of core areas has to be done. Effective science curricula have to coherently focus on important ideas within the discipline that are properly sequenced to optimize learning. The depth should ensure that the student has a basic, if not rigorous, understanding of the subject. The theoretical component of higher secondary science should strongly emphasize problem solving, awareness of conceptual pitfalls, and critical interrogation of different topics. Narratives giving insights on the historical development of key concepts of science should be integrated into the content judiciously. The teaching of the theoretical aspects and the experiments based on them should be closely integrated and dealt together. Some of the experiments must be open-ended, where there are no standard with expected results and there is scope for making hypotheses and interpretation of results.

With our emphasis on environment friendly materials, this is the stage to introduce microchemistry as a means of experimentation for the chemistry laboratory, and possibly also for some biology laboratory work. Use of micro chemical techniques has also the advantage of lower cost and greater safety [33].

The co-curricular activities at this stage could be of several types: adopting a problem-solving approach on local issues involving science and technology; participation through creative/investigative projects in national science fairs and participation in mathematics & science Olympiads. Students should be encouraged to participate in debates and discussions on issues at the interface of science, technology and society. Though these would form an important part of the learning process, they should not be included for formal assessment.

Since the curricular materials at this stage also cater to students who intend continuing in science as a career, and to sustain the enthusiasm of those who are prepared to handle more challenging materials, textbooks may carry some non-evaluative sections. In order to broaden the horizon of students for career choices available after the study of a science course, it seems useful if the career options are discussed, perhaps within the textbook itself.

The greater the variety of pedagogical approaches employed, the broader will be the range of learners reached. The enormous potential of ICT in science pedagogy should be exploited. (See 'ICT in Science Education'.) The classroom atmosphere should be such that it provokes questioning, discussions and debates and enhances students' meta cognitive skills.

The experiments and technological modules should be subject to continuous assessment even for the final Class XII examination. The theoretical papers including those for the Class XII external examination should have some experiment/ technology based test items. An important reform to reduce examination related stress is to permit students to accumulate marks/credits in different subjects at their own pace and not insist on their appearing for examination in all subjects at one go.

6. GOING FROM FORM TO SUBSTANCE: ADDRESSING SOME KEY ISSUES AND CONCERNS

The overall aims and approaches of the National Curriculum Frameworks in India over the past several decades have been largely unproblematic. They evolved in consonance with contemporary trends in education worldwide. In science education, the main problem has been the large gap that separates the curricular objectives and their implementation through syllabus, textbooks, classroom practices and examinations. It is important to address these concerns and formulate broad strategies so that the curriculum reforms do not simply remain 'on paper' but actually benefit the school system. We discuss some of these key issues and concerns in this section.

6.1 Infrastructure

The aims and objectives of education as envisaged by the curriculum require a certain minimum infrastructure for their meaningful implementation. Currently the infrastructure facilities are grossly inadequate in a great majority of schools. Every school must have basic facilities like a good building with adequate number of rooms, a playground, drinking water and toilet facilities. There are still many schools in the country which do not have potable water and toilets, let alone other facilities. Apart from these, science education requires some additional infrastructure.

Every primary school must have an activity room or an area where a class can assemble for individual or small-group activities. The activity room may house collections, charts, models and pictures assembled or prepared by students and teachers. Some essential equipment like hand-lenses, magnets, scissors, pen-knives and torch-light could be stored here. A large globe and models of body organs are some essential teaching aids. Puzzles, science toys, etc. could also be provided. Age-appropriate books from primary level upwards should be available to teachers and students. Teachers' resource books, popular science books, dictionaries, encyclopedias and other reference books should be provided. It may also be possible to build a small workshop with a set of basic tools for learning techniques of design and fabrication. Children should be encouraged to draw and write by converting three sides of the classroom into a blackboard at eye-level. For the upper primary stage, the activity room should be furnished to enable children to do simple experiments, and the school must have a workshop for designing models.

The facilities need to be substantially more advanced for the secondary and senior secondary stages, with well-planned laboratories, preferably Internet and multimedia facilities (at least for teachers) and a well-stocked library containing also career information materials. If the required facilities are not immediately possible in all schools, they must be available at least at the science resource centres and in mobile laboratories at the cluster, block and district levels. We should also remember that there are rich natural and human resources available in every kind of environment which could be utilized imaginatively.

Uneven distribution of infrastructure facilities in schools creates a large divide between them compromising the basic tenet of equality of opportunity enshrined in our constitution. Lack of facilities also has had another negative consequence. It has exerted pressure on curriculum designers and textbook writers to suit their work to the poor scenario of facilities and motivation. This in turn has led to a belief that space and practical work are luxuries, not essentials for science teaching. This cycle must be broken somewhere.

6.2 Syllabus, Textbooks and other Materials

Past experience shows that the ideals of a curriculum framework are greatly compromised in practice, beginning with the process of development of syllabus and textbooks. While formulating the curriculum, we should be aware that the teacher does not usually get to see the policy documents, and even if she does, she is more concerned with the textbooks that she has to use for teaching. Hence it is imperative that while preparing the curricular document, we should also prepare grounds for its translation into syllabi, textbooks and classroom processes. If we are to improve implementation we have to address several important issues.

6.2.1 Contextualization

The basic idea of a model curriculum at the national level should only be seen as a way to set uniform general standards of education throughout the country. A common syllabus (or small variations of it) and common textbooks are certainly not to be expected for the country as a whole. School systems in different states must devise their own curriculum. The larger states particularly need to reflect their diversity in their curricula. Within the broad guidelines of the curriculum framework the syllabi and the textbooks must allow space for contextualizing and variations at the local level for all stages of school education.

There have been attempts by various groups and autonomous institutions to develop alternative curricular books. But their use on a large scale is constrained by the rigidities of the curriculum prevailing in the school system, even at the elementary stages where more autonomy and flexibility is desirable and feasible.

The state structures of producing and distributing low-cost textbooks also remain geared for large scale printing of a single textbook. However, advances in printing technology now make it feasible to bring out several versions of a textbook to reflect regional, cultural and linguistic variations, since it is possible to keep costs low even for smaller print orders at very short notices.

6.2.2 Activity-based teaching

Though activity-based teaching has been accepted as a paradigm for science education and is also reflected in some measure in the textbooks developed at the national and state levels, it has hardly been translated to actual classroom practice. Activities still tend to be regarded as a way to verify the ideas / principles given in the text, rather than as a means for open-ended investigations. There is a general feeling that activity based teaching is expensive, takes more time that could be otherwise 'fruitfully' used for 'text based' teaching, and does not prepare the child for examinations and competitive tests.

The concern about expenditure involved in activities/experiments cannot be dismissed. Most schools cannot afford well-equipped science laboratories. However, it is certainly possible to design low cost activities and experiments using easily available materials. Thus cost should not be allowed to become an excuse for neglecting the very base of learning science. The concern regarding examinations can be addressed by reforms in the examination system that ensure due weightage to activities and experiments. (See 'Examination System'.) Overall, we need to develop textbook approaches, teaching styles and assessment procedures to ensure that meaningful learning does follow from activities.

6.2.3 Content

The most important consideration while developing a science curriculum is to ensure a reduced emphasis on mere information and provide greater exposure to what it means to practice science. The temptation for information overload stems from a concern with knowledge explosion and the need to put adequate information in a textbook. We should be wary of falling into this trap and should avoid ending up with a content-dominated curriculum that leaves insufficient time for discussion and reflection. We have already emphasized that scientific concepts introduced at any stage of the curriculum must be within the cognitive reach of the learner at that stage. While deciding content across grades we should steer away from the pipeline approach whereby some concepts get introduced too early for any meaningful understanding, on the grounds that they are required at a later stage. It must be realized that a difficult concept is not simplified merely by presenting it briefly, without rigour. Rather, the pre-requisites in terms of ideas, experiences and activities should be provided at the appropriate levels. We should avoid steep learning gradients, as currently existing between the secondary and higher secondary stages. Finally, pedagogy cannot be divorced from content—the two must be developed together.

In this paper we have recommended a much greater emphasis on creative expressions of students in non-formal ways both in and out of school activities, on practical work, on developing elementary technological modules, on surveys of biodiversity, health and other aspects of environment, etc. We have proposed that most of these should be exploratory / investigative activities outside the textbook. However, where naturally possible, parts of these activities should be imaginatively incorporated in textbooks.

6.2.4 Multiplicity of good textbooks

In an ideal education system, a textbook is only one of the diverse tools for curricular transaction. In India, for the great majority of school-going children, as also for their teachers, the textbook is the only accessible and affordable curriculum resource. Consequently, we must use the textbook as one of the primary instruments for universalization of good science education in the country.

Textbooks must help realize the basic curricular objectives of different stages, discussed earlier. A major problem today is the practice of rote learning, largely a result of the prevailing examination system[34]. Textbooks should help counter this tendency by raising meaningful and interesting questions, and by emphasizing applications and problem-solving. They should systematically establish linkages of many kinds with everyday experiences, within and between topics, between different curricular areas and across the years of schooling. Such linkages would form powerful reinforcers of learning.

To be fair to the past efforts in textbook-writing we must add that dealing with the various issues noted earlier is not an easy task. The problem is greatly compounded by the overpowering examination system that is discussed later. In any case, the development of a science curriculum that will satisfy the various criteria of validity is a highly challenging intellectual endeavour. Perhaps there is no single perfect solution to the problem. Perhaps there exist multiple partial solutions only, each suited to specific contexts. This is precisely why we recommend that curricular choices and textbook writing in our country should be characterized by diversity and alternative approaches. The national agencies should certainly continue their efforts to produce quality textbooks. States should be encouraged to develop multiple versions of their textbooks reflecting different local contexts; they could prepare different books for different districts, if possible. In case that is not possible, teachers and educationists should together prepare supplementary materials at local levels that can be integrated with the materials in the textbooks in use. Alternative writing of textbooks by individuals / NGOs / institutions should be encouraged. A reliable and efficient process of accreditation of the textbooks may be required to keep a check on purely commercial interests and to promote genuine creative textbook writing in the country.

6.2.5 Improving textbook writing procedures

There is a need to review the way the textbooks are written by national and state agencies. First, the syllabus should evolve along with the writing of the textbooks, keeping in view its consistency with the curricular objectives. Second, there should be greater participation of teachers in the actual writing of the textbooks. Third, we must set up a practice of intensive and widespread field trials of textbooks with involvement of teachers at all stages. Field testing is essential for, among other things, a cohesive integration of activities/experiments in the science textbooks. Traditions of testing, research inputs and feedback mechanisms must be institutionalized as part of textbook development. One serious problem has been that these tasks are often performed with unrealistic deadlines, leading to hasty production of books.

While the increasing use of four-colour printing is welcome, we are still far from fully realizing its potential. The best talent in designing is yet to be harnessed for producing quality textbooks. A conscious and concerted effort needs to be taken to fully exploit modern techniques of lay out, design and graphics.

Finally, textbooks at different stages should be split into suitably small sizes to avoid the physical burden of the school bag. The question of reducing other kinds of learning burden has been discussed earlier and is addressed through various recommendations in the paper.

6.3 Laboratory, Workshop and Library

A major area of concern is the gradual decline of practical work and experimentation at secondary and senior secondary levels, even while the concept of activity-based teaching is yet to become a living reality in our elementary schools. The oft-repeated recommendation of integrating experimental work and theory teaching has not been realized because of perceived lack of facilities and trained teachers in most of the schools. The degeneration of rigour in practical examinations has also lent weight to the argument to first remove them from the ambit of evaluation and then to trivialize or totally remove them from teaching practice itself. Often practical difficulties are cited as an excuse for this lack of commitment and awareness that experiment is fundamental to doing and learning science. Even well-endowed schools have tended to give only cosmetic importance to laboratory work in the prevailing scheme of things. We have already remarked that cost cannot be an excuse for neglecting experiments since it is possible to imaginatively design low cost science experiments.

Though experiments and allied activities in our system have been marginalized by the circumstance of not being externally assessed, it would be a wrong move to put them entirely within the ambit of an already dominating external examination. In this paper we have suggested a twofold approach to deal with the problem: (i) encourage practical / technological / creative components of the curriculum through non-formal channels, (ii) introduce some carefully designed experiment or technology-based questions in the theoretical paper itself. We are aware that this can only be an interim step to prevent the marginalization of experiments in school science curriculum. Ultimately, there is no alternative but to invest heavily in improving school laboratories and workshops while reducing the importance of external examinations and promoting experimental culture in our schools. We should also have computer-interfaced experiments and projects, besides projects utilizing database from the public domain.

Another point of concern is the great decline in the reading habit among children. Children need to be encouraged to read not only good textbooks but also a broad range of other materials to enrich their understanding. The nature of the extra curricular projects/ assignments should ensure the need for broader reading as well as an ability to search for the relevant materials. The school library should be adequately equipped to meet these requirements and schools should actively promote reading and referencing habits among children.

6.4 ICT in Science Education

Radio, and more recently television, has played a major role in the field of science communication. The SITE experiment in the mid-1970s was probably the biggest social experiment anywhere in the world that established the importance of satellite communication in the field of education.

Ever since, educational technology has come to be regarded as an important means for universalization of education in India. The widespread use of personal computers since nearly two decades ago, advances in telecommunication, and Internet a decade ago along with convergence of various technologies has, in the form of Information and Communication Technology (ICT), opened up new opportunities and challenges in the field of education.

Although the vast potential of ICT in the field of science education has been well recognized, it still remains largely untapped. The efforts have been piecemeal and sporadic. A beginning for introducing computers in the school system was made through the Computer Literacy and Studies in Schools (CLASS) project in the early 1980s. However, schools faced problems of infrastructure, appropriate software and lack of trained manpower. Today, the scenario has changed: with the increasing use of personal computers in schools, homes and workplaces, and internet connectivity, ICT shows renewed promise as a powerful tool for education, but only if these developments are complimented by making available quality software in different disciplines of science.

Appropriate multimedia software both in English and other Indian languages suited for various age groups in schools is still a rare commodity. Some steps have been taken by free software groups in different parts of the country to develop software localized in Indian languages. What we need now is a synergized and concerted effort in which Govt. agencies and NGOs working in this field pool their resources and expertise together. Development of software is an expensive affair and the Government should make sufficient funds available for the purpose. Software produced should be widely disseminated via Internet and CD-ROMs. Free software should be specifically promoted.

In terms of content, the Focus Group on Habitat and Learning has made a good beginning by proposing a country-wide open, transparent and publicly accessible information system on different facets of India's environment. Data on biodiversity, agriculture and health could be available here. Meteorological information could be disseminated quickly. Besides serving as a vital support for livelihood activities and disaster-management, the same system could be a rich learning resource for far-flung areas of the country.

The Internet opens up vast possibilities; it could provide an e-platform for discussion of topics relevant to school children both curricular and co-curricular where students and teachers could post queries, provide answers, discuss with experts and exchange views. Innovative scientific experiments using a PC could be designed for school students through a software and hardware interface to help students to measure common physical parameters (e.g. temperature, luminosity of light, humidity, etc), and also control these parameters. Such applications would serve to introduce the role of computers in industries, laboratories, communication and so on.

Launched on 20 September 2004, EDUSAT provides an interactive satellite-based distance education system for the country utilizing audiovisual medium, and employing Direct-To-Home (DTH) quality broadcast. With its multiple regional beams covering different parts of India and a beam covering the Indian mainland, it is possible to establish talk-back terminals - one way video and two way audio - for interactive programmes on science education. These would provide an interactive channel for students with experts and could include talks, lectures / demonstrations, discussions, question-answer sessions, etc. Talkback terminals and receive-only terminals could be set up at selected schools that could also be utilized by other schools in the neighborhood. To fully utilize the capabilities of EDUSAT, necessary hardware would need to be made available and efforts strengthened to produce quality software at regional levels.

The importance of community (FM) radio in science communication needs also to be emphasized. Such low-range community radio stations could be established at selected schools and the school students encouraged in producing science programmes relevant to the local areas. The audio channels of EduSat could beam such programs over wider areas. Participation in this activity could prove to be a great incentive in learning and communicating science.

Of late, Satellite Radio has opened up the possibility of a countrywide digital audio science channel. It can cover the remotest and most interior parts of a vast country like India with the help of a specially designed satellite radio receiver. This digital satellite communication radio system uses geosynchronous communication satellites dedicated for radio broadcasts and is essentially a direct-to-home radio (currently under the name World Space Radio). Access to news, educational broadcasts, and entertainment from all around the world through its unique global relay capability are the remarkable features of this system. Since the broadcast is digital, it is possible to download data files (sound as well as picture files) into a personal computer. It is hence possible to transmit and receive slides / visuals, store them in a personal computer, and synchronize with the audio broadcast for a full fledged lecture-cum-demonstration which can be projected on to a large screen to an entire class. Two-way interactivity is possible through telephone lines. In particular, production of software is relatively easy and cheaper to produce. Satellite Radio can prove to be an important tool for science communication / education in India.

ICT as a tool should be used with care so that it serves to bridge the social divide and equalize opportunity; inappropriate and insensitive use may as easily widen the divide. Given the growing reach of the technology, it is imperative that efforts are initiated to utilize ICT at the school level to prepare children to face the challenges of a society that is fast transforming into an information driven society.

6.5 Examination System

In the absence of a nationally co-ordinated effort in improving assessment methods, a conservative examination system continues to dictate what happens in science classrooms across the country. Its obsession with detention has generated deep fears and complexes in generations of children causing wastage and loss of human potential. Yet the system has acquired such a status that few dare to touch or challenge its basic premises. Its linkage with career options and social mobility has only had negative consequences, and we have yet to exploit the dynamism that this linkage could give to our education system.

No doubt, the various Examination Boards of the country are involved in continuous monitoring and change in their assessment practices. But the examinations system in India occupies such a central place in our entire education system that it ought to be debated in detail at the highest policy levels, and transformed radically throughout the country.

Pending such a much-needed revolutionary reform in the examination system, we have proposed an interim strategy in this paper. We suggest the following: Introduce creative, problem-solving, practical and technological elements in the curriculum, parts of which are outside the textbook and beyond assessment of any kind, while the remaining parts are imaginatively incorporated and integrated with the formal theoretical parts of the curriculum. The activities/experiments within the textbook would continue to be assessed internally even for the Class X and Class XII examinations. That leaves only the theoretical paper of Class X and Class XII for the external Board examination. We suggest that the theoretical paper itself should have some carefully designed problems as well as experiment and technology based questions. Some Examination Boards are contemplating such reforms and we welcome the idea.

Skeptics might regard our emphasis on non-formal creative components in the curriculum as unrealistic. ‘What is not assessed at the Board examination is never taught’ is the oft-repeated phrase. Still, we should not fall into the trap of putting everything we desire in the basket for external assessment. That will defeat the very purpose of introducing parts of the curriculum aimed at nurturing creativity and inventiveness. We must encourage these components by greatly strengthening and expanding non-formal co-curricular channels as recommended later in this paper.

But if Board examinations are here to stay at least in the foreseeable future, what steps should we take to improve them? There are two major deficiencies of the current examinations in science. First the science paper does not really assess genuine understanding of the subject. It mostly has formal theoretical questions, which can be handled by rote learning without much understanding. There are hardly any good unconventional questions, no challenging problems and no truly experiment / technology based questions. Second, for logistic reasons, the Board examinations are held on fixed days and times once (or twice) a year. If a student misses say the March examination of the Board for whatever reason, it essentially means loss of a full year. This feature coupled with the exaggerated importance attached to the external examination by students, parents and general public leads to a tremendously stressful situation for many young students leading even to such extreme steps as suicides. Alternatively, the circumstance generates unscrupulous and dishonest practices (leakage of papers, copying in the examinations, etc.).

In the past, efforts to improve the quality of external question papers have not had any significant success. The basic reason is that the Board examination is under incredible societal pressure. In a situation where even half a per cent of score up or down can affect the career prospects of a student dramatically (or so it is perceived), any reform that is seen to jeopardize the interest of students (in getting good scores) is bound to be greatly opposed and rejected under public pressure. Another thing that compounds the problem of improving the quality of the paper is that even a minor reform, if it is to succeed, should be in, due course, accepted by the numerous State Boards in the country, else the students from particular Board(s) would be seen to be at a relative advantage or disadvantage. But this universal acceptance of any significant reform by all the Boards is a near impossibility. In this situation the Boards at the national level can assume a leadership role. Reform might not be dramatic, but an incremental improvement in the quality of question papers is certainly possible. With all the present constraints and difficulties, questions at the external examinations <u>can</u> be made more meaningful and significant without necessarily increasing their difficulty level.

The second problem, namely of a one-time Board examination (for all subjects), perhaps can be handled in the future with the help of new technology. The Boards could introduce elaborate systems of on-line testing available at different times of the year. Students may write examinations in different subjects at different times and accumulate the necessary credits at their own pace – a facility that could greatly reduce examination related stress. This still does not look like an idea that can be immediately implemented and many problems of logistics and technology will need to be sorted out, but we feel the Boards may prepare themselves to think along this direction.

6.5.1 Entrance examinations after the (10 + 2) stage

The prestigious entrance examinations of the country in engineering and medicine have high standards of testing. They test problem-solving and critical reasoning abilities very well. This is what makes the best of Indian students at the +2 stage globally competitive in events like the International Olympiads. Yet these examinations are becoming an instrument of social divide. The gap between the academic demands of a conventional Board examination paper, and say, of IIT-JEE is so large (even though the syllabi are comparable) that a huge coaching industry is flourishing in the country to help students bridge the gap. The high cost of coaching puts students from rural areas and poorer homes at an obvious disadvantage, denying them access to quality education at the leading engineering/medical institutes of the country. The gap between the preparation for the Board examination and that for the premier entrance tests can be reduced only if schools discourage rote learning and emphasize problem solving. To ensure that this happens in all schools, the issues of equity that is our major concern must be addressed with high priority (See 'Equity and Science Education'.)

There is an additional problem with regard to entrance examinations after the (10 + 2) stage. The country has large numbers of these entrance examinations for admission to professional courses in engineering, medicine, information technology, etc.

after the (10+2) stage. In engineering, for example, besides the IIT-JEE and AIEEE, several states have their own entrance tests. In medicine we have entrance tests for AIIMS, JIPMER, AFMC, etc., besides again the medical entrance tests conducted by different states. In addition to the entrance examinations, there are other optional competitive examinations for NTSS, KVPY, Olympiads, etc. As if this was not enough, entrance and/or competitive examinations conducted by private colleges and agencies are proliferating throughout the country.

Because of the basic uncertainty about performance in any examination, most students (including very bright students) consider it prudent to appear for some half a dozen entrance tests to maximize their chance of admission to the courses/ institutions they desire to join. Though a quantitative study has not been undertaken, experience indicates a good correlation between many of these examinations. For example, students who are selected for NTS or Olympiad training camps (currently through independent examinations) nearly always do very well in IIT-JEE / medical entrance exams, as also in other entrance examinations. There is then a clear case for unloading our students by reducing the number of examinations they need to write after the (10 + 2) stage. This is also necessary since excessive preoccupation with preparation for entrance tests often affects students' interest and performance in the Board examination.

6.5.2 National Testing Service

We believe it is time to declare Examination Reform to be a National Mission (much like the other critical missions of the country) and to bring outstanding teachers, scientists and educationists on a common platform to carry out the mission. As a first step, we recommend that a comprehensive National Testing Service be launched. To begin with, the Testing Service could be confined only to the higher secondary stage. The proposal, if properly implemented, could have a number of beneficial effects. First, it would employ modern methods of evaluation (such as online testing) and enable students to appear for a test on a day / time of their choice. Also the students could appear for different subjects at different times and accumulate credits at their own pace. This should bring down the stress level of students considerably, as noted earlier. Second, the National Testing Service would greatly reduce the multiplicity of entrance and competitive examinations currently existing in the country. Third, and most important in the long run, the Testing Service can research on development of assessment tools for practical / technical skills, inventiveness and creativity, besides scholastic competence. A much wider range of ability and potential among students would then be tested, in contrast to the present situation. It should be clarified that this proposal is not quite the same as the National Testing Service proposed in NPE 1986.

We must, however, stress that the *National Testing Service* proposed here should be launched only if there is a commitment to treat Examination Reform as a mission supported by a funding that a critical mission deserves. The mission requires not only funding but also the services of very high quality human resources. The operational details of the proposed Testing Service would need to be carefully worked out before launching it. Additionally, consensus would need to be arrived at among the different central and state agencies for recognizing the *National Testing Service* and abandoning their own particular entrance examinations. Otherwise, the proposal may in fact be counter-productive, for it might add yet another examination to be cleared by students burdening them even more.

6.6 Co-curricular/Extra-curricular Activities

One of the objectives of science education is to develop inventiveness and creativity along with competence. Science education in India at its best develops competence, but does not encourage inventiveness and creativity. This is evident from the fact that many Indian students perform very well in formal / scholastic tests, but relatively few make it to the grade of truly outstanding researchers or original thinkers. An average science student in the country demonstrates neither inventiveness nor competence in science.

Curricular transaction alone is not sufficient to provide scope for inventiveness and creativity. This is particularly so in our education system, dominated as it is by the examination system. It is in this context that non-formal modes of learning assume great significance. It is through non-formal channels that creative learning could be encouraged by providing students an environment wherein they can undertake investigative science projects, develop innovative models / exhibits, or just tinker around with gadgets and machines. In many schools this kind of activity does exist in some form such as science exhibitions / science projects. Though it often assumes the form of an annual ritual, this is the only activity that allows non-formal interaction between students and science teachers and which stimulates innovation and creativity outside the classroom, if only in a small way. We see in it a big potential and recommend that a major effort be launched to convert this activity into a large-scale children's science movement in the country.

To go ahead in this direction, it would be imperative to provide a suitable forum like science clubs at schools with basic facilities like a few simple tools, measuring instruments, and a modest library. The activities of the clubs could range from individual projects to group projects. Schools should be given suitable grants to encourage this activity, but the schoolteacher should have academic freedom in guiding students to carry out the activity in consultation with local resource persons. Teachers would need to be oriented to help children engage in such activities. Training programmes should, therefore, include sessions on the importance and organization of creative science activities. Teachers' handbooks may be prepared for the purpose listing relevant software publications, audio / video programmes, learning modules, activity kits, etc. developed by organizations engaged in innovative science education.

Science clubs could be affiliated to existing national networks of science clubs and even could play an important role in communicating science and technology to the general public by undertaking campaigns on occasions like total solar / lunar eclipses, National Science Day, etc. under the guidance of the school teachers. We emphasize that this activity should be free from student assessment, internal or external. Achievements of students in extra-curricular activities and the teachers' contribution, however, would need to be recognized suitably.

Schools should be encouraged to participate at local/state/national levels in activities like the Children's Science Congress (organized by NCSTC) and the science exhibitions (organized by NCERT and NCSM at the national and regional levels respectively). We suggest that these different agencies join hands, consolidate their efforts by sharing their resources and experiences and take steps to launch a large scale SCIENCE AND TECHNOLOGY FAIR at the national level, with smaller feeder fairs at state / local levels.

It is important to realize that co-curricular and extra curricular components should not be viewed as a marginal part of the school curriculum. In fact, in the present system of examination-dominated education in the country, it seems to be the only way to promote inventiveness and creativity. A change in mindset is, therefore, required to give the activity a big boost through massive Government support and large-scale promotional efforts involving the participation of students, teachers, teacher associations, NGOs and other stakeholders. We must take care that the activity does not degenerate into just grand annual rituals. There should be efforts for improving the quality of projects and ensuring that they are genuinely investigative and exploratory in character, and require innovation and creativity.

6.7 Teacher Empowerment

The issue of teacher empowerment has been discussed and debated for a long time. The present models of teacher preparation have not really succeeded to empower science teachers. Therefore, it is imperative to restructure the policies and practices in teacher empowerment programmes. A renewed effort towards preparation of quality teachers should gain overriding priority in the new National Curriculum Framework. This is a non-negotiable prerequisite to ensure the realization of the goals and objectives of the envisaged science curriculum.

Raising the motivational levels of the teachers has been a great challenge. Although there are no ready-made solutions to this vexed problem, we still believe it is not entirely insurmountable. Systemic improvements, better recruitment policies, increased salary grades and other material benefits and establishment of appropriate support systems will improve the situation. It will help to attract the right kind of people to the profession. Lack of confidence and motivation often result from lack of empowerment and absence of freedom. The authoritarian pressure of the higher-ups, top-down models of decision making, unreasonable expectations in the name of 'accountability' and duties unrelated to teaching are compounding the problem. Teachers' voice is rarely given space in educational decision- making except as a token. There is a need to change this scenario.

A complete overhaul of the teacher education system in the country, including modernization of syllabus, development of appropriate laboratories for teacher education in science and a vigorous recruitment of high quality teacher educators is the need of the hour. Teacher educators in science should have a certain minimum experience of teaching science at the appropriate level. Presently, there is no substantive mechanism for facilitating the professional development of science teacher educators. The present teacher education curriculum has a strong bias in favour of theory. A complete reformation of the teacher education curriculum should encompass the following:

- The science teacher preparation curriculum should be in consonance with changing priorities and challenges of the times. Any major change in the school science curriculum should necessarily involve concomitant changes in the teacher education curriculum. Inadequacies in the pre-service education of science teachers cannot be compensated through in-service programmes.
- The science teacher education curriculum should be based on all the critical skills and competencies expected of science teachers.
- Science teacher preparation curriculum should emphasize process skills and methodological aspects of science, and should be informed by historical and developmental perspective of science.
- There should be a concerted move towards integrated teacher preparation programmes spread over 4-5 years.

In-service programmes too need revamping. The quality of most in-service programmes is questionable. We recommend that all in-service programmes for science teachers should be need-based. Ways and means of assessment of needs will have to be developed. Need assessment should be undertaken on a continual basis. It is practically impossible to provide in-service education to all science teachers in 'face-to-face' mode within a reasonable time frame and with limited resources. Distance learning options for teacher empowerment should be put in place. On-line courses and websites for each class level could be another potential option.

Teachers get about 60 days of vacation in a year. A good part of this should be meant for professional improvement. Most of the in-service programmes should be organized during these breaks. However, they may be compensated suitably by providing leave. Teachers should be encouraged to display self-directedness and responsibility for honing their professional competence.

One of the most important ways of teacher empowerment is to create effective systems for peer group interaction. Within-school mechanisms of mentoring and discussions between teacher colleagues should be established. Currently the interaction between colleagues tends to be largely non-academic. Science teachers could come together and form their own forum to discuss academic matters. The CRCs and BRCs could nucleate this process. Teacher manuals, magazines for science teachers, organizing seminars, symposia, exhibitions, science melas, interactions with scientists and educationists of eminence, can all contribute to the development of quality in teachers.

Teacher empowerment is the overarching reform under which all other reforms and recommendations given in this paper should be positioned. For, if we do not empower teachers, they are bound to show in difference /resistance to any new ideas, no matter how sound they look to educationists.

6.8 Equity and Science Education

Equity is the fundamental goal of any democratic society such as ours. Yet, so far, the system has failed to address the issue of quality science education 'for all' adequately. Many students come out of schools as 'scientific illiterates' or would soon lapse into this state. This is basically because many groups of students are placed in a disadvantageous position vis-à-vis learning of science. The disadvantaged groups include girls, children from rural areas, tribal and other socio-economically underprivileged children in rural as well as urban areas, those with learning difficulties and physically challenged children. Learning needs of these disadvantaged groups require greater attention. The system, in general, and the teachers in particular have to be sensitive to the needs of these diverse groups of children.

Science learning should be used as an instrument of social change to reduce the socio-economic divide. It should help to fight prejudice related to, among others, gender, caste, religion and region. Science education ought to empower students to question the social beliefs, notions and practices that perpetuate social inequality.

Given the low levels of literacy and schooling in the country, the majority of students are first generation learners. In this context education is often blamed for bringing about an alienation of the child from the family and society. However it is possible in the design of the curriculum to build close connections with the local environment and to also involve the adults in the society in the child's learning. Locally situated technology education too should serve to integrate the child into the society. Sensitivity in the choice of contexts, of equipment and pictures, could go a long way towards reducing inequality.

Ensuring access to schooling for all children is in itself not sufficient. The system must take proactive measures to ensure access to education (in this context science education) of reasonable quality. The twin objectives of access and quality should go together and never one after another.

6.8.1 Towards bridging the rural-urban divide

There exists a huge gap in the education in general and science education in particular between the rural and urban students. The inequality, among other things, is mainly due to poor infrastructure, inadequate support systems, lack of access to information and other resources in rural areas, and a clear urban bias in various educational inputs. We have already emphasized that a certain minimum infrastructure and academic support in all schools is a prerequisite for good science education in the country. (See ' Infrastructure'.)

In terms of content, we should ensure that rural lifestyles are reflected in the curriculum, which can be done very effectively in contextualized curricula. Basic issues like food and water should be dealt with in the context of an agrarian economy rather than as de-contextualized isolated topics in the textbook. Various kinds of occupations engaged in by rural people, including the tools and techniques of different trades, should find place in the curriculum.

A 'rural science movement' should be initiated by organizing science programmes like demonstrations, science camps and science exhibitions at the cluster level and block level. Exhibitions on the theme of rural technologies may also be appropriate. The state departments of education through its agencies (like BRCs and CRCs) in collaboration with NGOs (wherever possible) may organize 'science camps' for rural children during vacation.

Similarly the potential of 'village radio stations' may be explored to provide opportunities for rural children to take part in 'radio science programmes'. Efforts are needed to pass on the benefits of science learning even to students who somehow happen to remain outside the school system. Rural radio science programmes may serve this objective at least partly.

Students from rural schools usually study science in their mother tongue/local language up to Class X. Many places offer +2 course only in the English medium. Even where the course is offered in the local language, a level playing field rarely exists. Lack of textbooks, lack of teachers available, dearth of reference books are a few of the many problems these students encounter. This puts rural children at a great disadvantage. Special programmes to increase the competence of rural students in English are needed. Further, efforts should be strengthened not only to offer +2 science course in the local language, but also to provide the required facilities to study in the local language.

Rural children have little or no access to educational and career information in science. Guidance centres may be set up in each taluka to cater to the needs of the rural children. Similar efforts are required to provide facilities for helping rural children for competitive examinations in science.

6.8.2 Gender and science education

Studies have shown that girls in the same class get science education different from boys. Science textbooks and science teachers, like others, are not free from gender bias. Science teachers too carry the same gender stereotypes as others. More discerning efforts are needed to remove gender bias from textbooks and classroom practices. Gender sensitization of teachers both at the pre-service stage and during in-service training is critical to promote gender fair science education. Further measures (including motivating the parents) are needed to encourage more girls to pursue science education and careers in science and technology.

The curriculum should strive to make the contribution of women to the field of science and technology 'visible'. Teachers should be sensitized to promote equitable classroom practices to ensure 'science experiences' of comparable quality to girls. Teachers, teacher educators, textbook writers and educational administrators are to be made sensitive and responsive to gender related issues. Studies should be undertaken to understand how gender bias operates in schools both within and outside the classrooms. Teachers should be exposed to the insights from such studies.

6.8.3 Needs of other disadvantaged groups

There are other sections / groups of students whose needs are unique. This is a specialized area and techniques of teaching need to evolve in consultation with the concerned experts. The system should display the courage of conviction to mobilize required resources to put in place support systems that will help these children to overcome their inadequacies in learning science in a meaningful manner. The recommendations of the focus groups concerned with these issues may be the basis for attending to the 'science needs' of these children.

We recall again that all such inequities are reflected in the high drop-out in our school system which therefore has a clear stake and responsibility in the matter.

7. RECOMMENDATIONS

For convenience, we summarize the key recommendations of this report, particularly highlighting those that in our view are either new or have received greater emphasis in this paper than before. Some of the recommendations state principles and paradigms, while some others are prescriptive in nature and focus on action. The justification/ explanation of the various recommendations appears in the main body of the report.

7.1 Criteria of Ideal Science Curriculum

We regard good science education as one that is true to the child, true to life and true to science. This simple and natural observation leads to six basic criteria of validity (cognitive, content, process, historical, environmental and ethical) of a science curriculum, as already explained. The general aims of science education follow directly from these criteria of validity.

7.2 Science Curriculum at Different Stages

Consistent with the general aims, the objectives, content, pedagogy and assessment for different stages of the curriculum are summarized below.

At the primary stage the child should be engaged in joyfully exploring the world around and harmonizing with it. The objectives at this stage are to nurture the curiosity of the child about the world (natural environment, artifacts and people), to engage in exploratory and hands on activities to acquire the basic cognitive skills (psychomotor, observation, classification, inference, etc.); to emphasize on design and fabrication, estimation and measurement as a prelude to development of technological and quantitative skills of later stages; and to develop basic language skills: speaking, reading and writing not only for science but also through science. Science and social science should be integrated as '*Environmental Studies*' as at present, with health as an important component.

Throughout the primary stage, there should be no formal periodic tests, no awarding of grades or marks, and no detention.

At the upper primary stage the child should be engaged in learning simple principles of science through familiar experiences, in working with hands to design simple technological units and modules and in continuing to learn more on the environment through activities and surveys. Scientific concepts are to be arrived at mainly from activities and experiments. Science content at this stage is not to be regarded as a diluted version of secondary stage science. Group activity, discussions with peers and teachers, surveys, organization of data and their display through exhibitions, etc. in schools and neighbourhood are to be an important component of pedagogy. There should be continuous as well as periodic assessment (unit tests, term end tests). The system of 'direct' grades should be adopted. There should be no detention. Every child who attends eight years of school should be eligible to enter Class IX.

At the secondary stage the students should be engaged in learning science as a composite discipline, in working with hands and tools to design more advanced technological modules than at the upper primary stage, and in activities and analysis on issues surrounding environment and health. Systematic experimentation as a tool to discover/verify theoretical principles, and working on locally significant projects involving science and technology are to be important parts of the curriculum at this stage.

At the higher secondary stage science should be introduced as separate disciplines with emphasis on experiments/technology and problem solving. The current two streams, academic and vocational, being pursued as per NPE 1986 may require a fresh look in the present scenario. The students may be given an option to choose the subjects of their interest freely, though it may not be feasible to offer all the different subjects in every school. The curriculum load should be rationalized to avoid the steep gradient between secondary and higher secondary syllabus. At this stage, core topics of a discipline, taking into account recent advances, should be carefully identified and treated with appropriate rigour and depth. The tendency to superficially cover a large number of topics of the discipline should be avoided.

7.3 Stimulating Creativity and Inventiveness in Science

- Introduce a paradigm shift in science curriculum at all stages. Emphasise exploration, inventiveness and creativity through activities, experiments, technological modules, contextualized as far as possible. Encourage implementation of co-curricular and extra curricula components through a massive expansion of existing non-formal channels such as project exhibitions, children's science congress, etc.
- In continuation of the measure above, launch a large scale SCIENCE & TECHNOLOGY FAIR at the national level for school students, with feeder events at local/district/state levels, with the objective of searching and nurturing inventive/creative talent among students. Upgrade the current activity in this regard by many orders of magnitude, through co-ordination of state and central agencies, NGOs, teacher associations, etc., financial support and mobilization of experts in the country.
- Incorporate experiments/technological modules and other parts of co-curricular components into the textbook as far as

feasible, which should be subject to internal assessment (even for Class X and Class XII examinations). Other co-curricular components should be encouraged through non-formal channels as suggested before.

7.4 Textbooks

- Use the textbook as one of the primary instruments for universalization of good science education in the country, since for a great majority of school going children,especially from rural areas and poor homes, as also for their teachers, it is the only accessible and affordable resource for education.
- Encourage diversity of curricular choices and alternative approaches to textbook writing in the country, within the broad guidelines of the national curriculum framework.
- Improve textbook writing procedures by the national and state agencies. Ensure greater participation of teachers in the actual writing of the books and their intensive field testing.

7.5 Examination System

- The activities/experiments/technological modules within the textbook should be assessed internally even for Class X and Class XII Board Examinations.
- The theoretical science paper for examinations including the Class X and Class XII Board examinations should have carefully designed experiment/technology-based questions, questions testing critical understanding and ability to solve problems.
- Permit students to write examinations in different subjects at different times and accumulate credits. There may be problems of logistics in implementing this idea at present, but it will reduce examination related stress to some extent.
- Reduce multiplicity of entrance examinations after the "10 + 2" stage by coordination of various central and state agencies. Launch a comprehensive *National Testing Service* (at the higher secondary stage, to begin with) as a possible way to reduce this multiplicity. **The proposal is feasible only if the different central and state agencies agree to drop their entrance examinations in favour of a common *National Testing Service*; otherwise the proposal may be counterproductive.**

7.6 Teacher Empowerment

- Carry out a complete overhaul of the teacher education system in the country including modernization of syllabus and development of appropriate laboratories for teacher education in science.
- Undertake vigorous recruitment of high quality teacher educators who must have actual experience in school teaching.
- Undertake orientation of inspectors and government educational officials and sensitize them to the need for academic autonomy of teachers, without sacrificing academic accountability.
- Provide qualified and trained teachers at all stages.
- Create systems of peer group interaction among teachers. Promote within school and between schools modes of academic exchanges between teachers.
- Discontinue the practice of giving extraneous non-academic responsibilities to teachers at the cost of their teaching duties.
- Institute schemes of incentives/awards to honour the deserving teachers.

7.7 Equity

- Use science curriculum as an instrument of social change to reduce the socio-economic divide and to help fight prejudice related to gender, caste, religion and region.
- Content of the curriculum should promote respect for diverse lifestyles, even if there is a focus on contextualization.
- Emphasise gender sensitisation of teachers both at the pre-service stage and during in-service training to promote gender fair science education.
- Use ICT as a powerful tool for bridging the social divide in education and as an opportunity equaliser.

8. OUTLOOK

For the last many decades, science education in India has been an enterprise of unresolved dichotomies and contradictions. For almost three decades now, science is a compulsory subject up to Class X throughout the country, yet this universal science education continues to be largely irrelevant to most students and its quality unacceptably poor. The over-all conceptualization of science curriculum at the national level has matured steadily and kept pace with evolving contemporary trends in science education the world over; yet this has hardly translated into any significant improvement in the actual teaching of science. There have been notable innovative efforts by several NGOs and other institutions, sometimes in collaboration with central and state agencies, yet these efforts have not qualitatively improved the mainstream science education. For an overwhelming majority of students, science is just another demanding and difficult subject to be learnt by rote, with no meaningful learning outcomes whatsoever, yet a small minority of students do come out of the system with outstanding competence in science comparable to international standards. Amidst the large number of unmotivated, unprepared teachers, some do transcend the limitations of the system and become inspiring models to students. In short, there are small islands of excellence in different domains in a sea of mediocrity and irrelevance.

Looking at the complex scenario of science education in India, three issues stand out unmistakably. First, science education is still far from achieving the goal of equity enshrined in our constitution. Second, science education in India, even at its best, develops competence but does not encourage inventiveness and creativity. Third, the overpowering examination system is basic to most, if not all, the fundamental problems of science education in India.

In this position paper, the Focus Group has attempted to address a range of issues related to science curriculum and problems in its implementation, but has particularly focused on the three issues mentioned above. First, we must use the science curriculum as an instrument of social change to reduce the divide related to economic class, gender, caste, religion and region. We must use the textbook as one of the primary instruments for equity, since for a great majority of school going children, as also for their teachers, it is the only accessible and affordable resource for education. We must encourage alternative textbook writing in the country within the broad guidelines of the national curriculum framework. Information and Communication Technology (ICT) is also an important tool for bridging the social divides. ICT should be used in such a way that it becomes an opportunity equalizer, by providing information, communication and computing resources in remote areas.

Second, we believe that for any qualitative change from the present situation, science education in India must undergo a paradigm shift. Rote learning should be discouraged. Inquiry skills should be supported and strengthened by language, design and quantitative skills. Schools should give much greater emphasis on co-curricular and extra curricular elements aimed at stimulating investigative ability, inventiveness and creativity, even if these elements are not part of the external examination system. We strongly recommend a massive expansion of non-formal channels (for example, a truly large scale SCIENCE & TECHNOLOGY FAIR with feeder fairs at cluster/ district/state levels) to encourage schools and teachers to implement this paradigm shift.

Third, we recommend nothing short of declaring examination reform as a National Mission (like other critical missions of the country), supported by funding and high quality human resources that such a mission demands. The mission should bring scientists, technologists, educationists and teachers on a common platform and launch new ways of testing students which would reduce the high level of examination related stress, curb the maddening multiplicity of entrance examinations, and research on ways of testing multiple abilities other than formal scholastic competence.

These reforms, however, fundamentally need the over arching reform of teacher empowerment. No reform, however well motivated and well-planned, can succeed unless a majority of teachers feel empowered to put it in practice. With active teacher participation, the reforms suggested above could have a cascading effect on all stages of science teaching in our schools.

REFERENCES

Kelly, A. E. and Lesh, R. A. (2000) *Handbook of Research Design in Mathematics and Science Education.* Lawrence Erlbaum Associates, Mahwah, New Jersey.

White, R. (2001) The revolution in research on science teaching. In Virginia Richardson (Ed.) *Handbook of Research on Teaching* (4th Edition), American Educational Research Association, Washington, D. C..

Berliner, D. C. (2002) Educational research: the hardest science of all. *Educational Researcher,* 31 (8), 18-20.

Fraser, B. J. (1998) Science learning environments: Assessment, effects and determinants. In Fraser, B. J. and Tobin, K. G. (Eds.) *International Handbook of Science Teaching* (Part 1). Kluwer Academic, Dodrecht, The Netherlands.

Shapiro, B. (1998) Reading the furniture: The semiotic interpretation of science learning environments. In Fraser, B. J. and Tobin, K. G. (Eds.) International Handbook of Science Teaching (Part 1). Kluwer Academic, Dodrecht, The Netherlands.

Stepanek, J. (2000) *It's Just Good Teaching.* Mathematics and Science Education Center, Northwest Regional Educational Laboratory, Portland, Oregon. http://www.nwrel.org/msec/science_inq/whatisinq.html

Duschl, R. A. (1985) Twenty five years of mutually exclusive development: new science curricula and the philosophy of science, School Science and Mathematics, Vol. LXXXV, November 1985, 541-55.

Lederman, N. (1992) Students' and teachers' conceptions of the nature of science: A review of research. *Journal of Research in Science Teaching,* 29 (4), 331-359.

Driver, R. (1975) "The name of the game." School Science Review, 56 (197), 800-04.

Wellington, J. (1981) *"What's supposed to happen sir? Some problems with discovery learning." School Science Review,* September, 167-173.

Ramadas, J., Natarajan, C., Chunawala, S. and Apte, S. (1996) Role of Experiments in School Science. Diagnosing Learning in Primary Science - Part 3. Homi Bhabha Centre for Science Education, Mumbai.

Carey, S., Evans, R., Honda, M., Jay, E. and Ungar, C. (1989) "An experiment is when you try it and see if it works: A study of grade 7 students' understanding of the construction of scientific knowledge." *International Journal of Science Education,* 11 (5), 514-29.

Vosniadou, S. and Ortony, A. (Eds.) (1989) *Similarity and Analogical Reasoning.* Cambridge University Press, Cambridge.

Sutton, C. (1992) *Words, Science and Learning.* Open University Press, Buckingham.

Sayers, R. (1992) *Cultural and Linguistic Factors in Mathematics and Science Education*: An Annotated Bibiography. Centre for Studies in Science and Maths Education, University of Leeds.

Kulkarni, V. G. and Gambhir, V. G. (1981) *"The effect of language barrier on the universalisation of education*." *Indian Educational Review.* January 1981.

Driver, R. and Easley, J. (1978) "Pupils and paradigms:" A review of reasearch related to concept development in adolescent science students, *Studies in Science Education*, 5, 61-84.

Driver, R., Squires, A., Rushworth, P. and Wood-Robinson V. (1994) Making Sense of Secondary Science: *Research into Children's Ideas.* London: Routledge.

Natarajan, C., Chunawala, S., Apte, S. and Ramadas, J. (1996) *Students' Ideas about Plants. Diagnosing Learning in Primary Science - Part 2.* Homi Bhabha Centre for Science Education, Mumbai.

Mahajan, B. and Chunawala, S. (1999) Indian secondary students' understanding of different aspects of health. *International Journal of Science Education,* 21 (11), 1155-68.

Carey, S. (1986) "Cognitive science and science education." *American Psychologist*, 41 (10), 1123-1130.

Chi, M. T. H., Feltovich, P. J. and Glaser, R. (1981) "Categorization and representation of physics problems by experts and novices," *Cognitive Science*, 5, 121-152.

Larkin, J., McDermott, J., Simon, D. P. and Simon, H. A. (1980) *"Expert and novice performances in solving physics problems," Science*, 208, 1335-1342.

Mintzes J., Wandersee, J. and Novak, J. (Eds.) (2000) *Assessing Science Understanding: A Human Constructivist View.* Educational Psychology Series. Academic Press, San Diego, CA.

Broadfoot, P. M. (1996) *Education, Assessment and Society: A Sociological Analysis.* Open University Press, Buckingham and Philadelphia.

Ministry of Education (1966) *Education and National Development*: *Report of the Education Commission* 1964-66. Reprinted in 1971 by NCERT, New Delhi.

NCERT (1975) *The Curriculum for the Ten-Year School.* National Council of Educational Research and Training (NCERT), New Delhi.

NCERT (1988) *National Curriculum for Elementary and Secondary Education - A Framework (revised version).* National Council of Educational Research and Training (NCERT), New Delhi.

NCERT (2000) *National Curriculum Framework for School Education.* National Council of Educational Research and Training (NCERT), New Delhi.

Kumar, K., Priyam, M. and Saxena, S. (2001) *"Looking beyond the smokescreen:"* DPEP and primary education in India. *Economic and Political Weekly.* EPW Special Articles, February 17, 2001.

Indian NGOs (2002) *Status of Coverage of Non-DPEP Districts Under SSA* (Revised as on 15-1-2002) http://www.indianngos.com/issue/education/ govt/project2.htm

Dhankar, R. (2003) "*The notion of quality in DPEP pedagogical interventions.*" *Education Dialogue.* Volume 1:1, Monsoon 2003. 5-34.

Bhanumathi,S. 1994. *"Small scale chemical techniques."* *Chemistry Education* (April-June) : 20-25.

Ministry of HRD (1993) Learning Without Burden: *Report of the Advisory Committee appointed by the Ministry of Human Resource Development* (MHRD), Department of Education, New Delhi.

ABBREVIATIONS

AFMC	Armed Force Medical College
AIEEE	All India Engineering Entrance Examination
AIIMS	All India Institute of Medical Sciences
BRC	Block Resource Centre
CLASS	Computer Literacy and Studies in Schools
CRC	Cluster Resource Centre
DTH	Direct-To-Home
DPEP	District Primary Education Programme
HSTP	Hoshangabad Science Teaching Programme
ICT	Information and Communication Technology
KVPY	Kishore Vaigyanik Protsahan Yojana
IIT-JEE	Indian Institute of Technology-Joint Entrance Examination
JIPMER	Jawaharlal Institute of Post-Graduate Medical Education & Research
LJ	Lok Jumbish
MHRD	Ministry of Human Resource Development
NCERT	National Council of Educational Research and Training
NCSM	National Council of Science Museums
NCSTC	National Council for Science & Technology Communication
NPE	National Policy on Education
NCF-88	National Curriculum for Primary and Secondary Education – A Framework
NGO	Non-Govt. Organization
NTSS	National Talent Search Scheme
SITE	Satellite Instructional Television Experiment
STL	Scientific and Technological Literacy
SSA	Sarva Shiksha Abhiyan
UNICEF	United Nations International Children's Emergency Fund
UGC	United Grants Commission
UT	Union Territory