19

Science Education

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THE NATURE OF SCIENCE

We live in exciting times for it is the century of science and technology. It is also the century of the child: Montessorian, Froebellian, Piagetian, Gandhian, or for that matter Brunerian—parts of each for all the time. But what is science? Science is a great human enterprise, not only endless and faceless but also stable and fluid. It is a self-accumulating, self-growing, self-pervading, self-accelerating and self-correcting enterprise which originated in the collective curiosity of man since time immemorial. It attempts to provide a body of knowledge through procedures that are demonstratively objective but often done in a subjective context. It is as objective as the prevailing conditions make it, that is, do not challenge it. In every generation, it operates in a certain frame of reference which yields imperceptibly to another, later on. It moves forward on the wheels of dogmatism, dynamism and discovery at the same time. Open-mindedness, curiosity, inquiring into the basis of all things, collection of data, demand for verification and proofs, statistical reasoning, suspended judgments, acceptance of warranted conclusions and willingness to change one's opinion in the light of new evidence are the ferments which characterise the scientific enterprise. The central message relevant to our context is more specific when Lord Buddha asked us to reason out truth (add verifications) and if convinced "live up to it and help others to live up to it". Any country which keeps her children bereft of this investigative aspect of science is stealing the seeds of her future in science and other fields intimately related to it such as engineering, technology and other helping professions, etc.

SCIENCE EDUCATION

If we throw a bridge between science and education, using psychology, we arrive at the concept of science education, which, bluntly speaking, is an integrated concept. If so, it is then within the realm of possibility to link the most powerful concepts of science to the growing minds of children through active experimental pedagogy. In that case, science education need no longer remain a single-dimension activity. It would be our job then to develop the scientific and technical capabilities of our schoolgoing pupils. We may be then able to win our race in education in the 21st century. To achieve this end, we have then to walk confidently on a continuum somewhat as follows:

Scientific knowledge	→	Scientific literacy	→	Social action	→	Productivity/ prosperity for the society	→	Quality of life

The field of science education is, thus, coterminous with life. This view promotes as well the inherent value system of science on a very large scale. It is precisely for this reason that research in science is needed and, if so, needs to be produced for relevance at an early hour.

PAST RESEARCH IN SCIENCE EDUCATION

Science, it is said, speaks to the mind. Science education, on the other hand, ought to speak to the mind as well as to the flesh (hand). Ganguli, D. and Vashistha, U.C. 1991, in their trend report on Research in Science Education for the Fourth Survey pointed out the various weaknesses of science education. The competence of science teachers, for example, is manifested when they are in a position to reach out to different children by creating a rich multi-dimensional environment for them to learn. They have no choice but to think hard while working on their jobs. Otherwise, it may happen that curriculum framers, examination boards, publishers, science teachers and science students may be stealing each other's clothes for the benefit of none. Ganguli, D. and Vashistha, U.C. (1991) listed 101 researches in eight areas which were conducted during the first four surveys, including their own research.

Without commenting on the quality of the research conducted so far, even the frequency of researches conducted over the first four surveys was just meagre, a mere total of 101 studies. It is, really speaking, a dismal picture considering the vastness of the country which in sheer size is equal to the whole of Europe minus the former U.S.S.R. In the present survey, like in the fourth survey, the number of studies has not changed (61 studies). If small changes in items under the various areas of science education along unilateral classification are made for better focus, the picture emerges as presented below in Tables 1 and 2. It is true that we did not have the benefit of personalities indigenously produced, such as those of H.E. Armstrong in England; Max Wertheimer (Germany), Jean Piaget (Switzerland); L.S. Vygotsky (former USSR); and B.F. Skinner, J.S. Bruner, B.S. Bloom and David Ausubel (USA). However, we had personalities of everlasting influence such as Gandhi, Nehru, Zakir Hussain, and Tagore. We had the benefit of the National Council of Educational Research and Training, New Delhi, her counterparts in the States of the Union and the All India Science Teachers Association, New Delhi, as well as some voluntary organisations such as the Hoshungabad Science Teaching Project in Madhya Pradesh. Lastly, taking an overall view, we did have the benefit of published researches, method texts, teacher's guides, production of scientific equipment and the cheapest ever educational journals such as *School Science* (NCERT, New Delhi). Result: The ship of science education is on the high seas, moving rudderless with no Pole Star in sight for guiding our journey. Its maladies are self-evident. If it is a case of systems failure, we have then unilaterally disarmed ourselves almost at every point favouring decadence in school science education. There is no hope for improvement of school science in our country until and unless both the blind and the leper, as the Sufi story goes, take each other's help for getting out of the curricular jungle. These blind men and lepers, metamorphically speaking, are our content-oriented and education-oriented science education experts and teachers. It won't be a case of exaggeration if it is added that every straw that we need to develop science education exists in our country, international help and experience, of course, not excluded.

REVIEW OF RESEARCHES IN SCIENCE EDUCATION (1982-92)

Environmental Studies

Science need not be taught by word of mouth. It also need not be taught in an authoritarian manner by chalk-and-talk methods alone. Progressive educators like John Deway and M. Montessory; M. Gandhi and Jean Piaget; L.S. Vygotsky stressed activity methods, productive methods and experimental pedagogy in their reaction to traditional education. It received a thrashing at the hands of several critics and was termed as "soft education". With the flight of *Sputnik* in space by the Russians in 1957, a revolution in science teaching and education took place which raged fiercely in the entire English-speaking world in the sixties and seventies (Vaidya, N. 1989). Veerappa (Ganguli, D. and Vashistha, U.C., 1991) assessed the position of science teaching in India which was characterised by the "Herbertian" plane, lecture/lecture-cum-demonstration method and essay-type examinations. Nothing of educational value is lost if children are taken away for varying lengths of time from the classroom with a view to study the local environment in which they live. They become lively in this environment because their basic needs are met: Need to know, Need to inquire, Need to relate, Need to test their ideas, and finally, Need to be creative. Rural children also become the major beneficiaries, for the abstract modern curricula may be lost on them. Science for them, too, needs to be taught as a tool subject for the development of their logical reasoning/rational thinking, and consequently, as a remedy of obscurantism. It is equally useful for socially disadvantaged groups. Precisely for this reason, it is very necessary to grow science about the local environment. Here researchers visualise two sets of studies. First, the environment is explored in its content; and secondly, it is explored as a teaching-learning resource in a wider setting. Regardless of the mode of exploration or purpose, both the modes can be bent fruitfully for educational purposes right from primary education through secondary education to even higher education, including teacher education. In whatever way one sees the past studies by Exemmal (1980), Depuria (1981), Pai (1981), Joshi (1979), these firmly support the view that environmental studies aid cognitive growth; rural children, and those too from the Low Socio-economic Status, gain more from this approach to learning than their counterparts in the urban areas; and finally, even male and female science teachers hold favourable attitudes towards the teaching of environmental studies. Interestingly enough, it is highly relevant to the education of primary school-children. The same findings almost appeared when the scope of environmental studies was extended to several rural and urban schools as well as non-formal education centres. Similar work by the Central Regional Centre and the State Council of Educational Research and Training (A.P.) almost confirmed what has already been said above (Ganguli, D. and Vashistha, U.C. 1991).

Table 1
Frequency of Researches Conducted in Various Areas of Science Education

Sl. No.	*Area of Science Education*	*No. of Studies*
1.	Philosophy of Science/Scientific Method/ Nature of Science	-
2.	Historical Studies, including Comparative studies in Science Education	-
3.	Policy studies	-
4.	Environmental studies	9
5.	Science Curriculum Syllabus and Textbook	7
6.	Learning Science and Models of Teaching	15
7.	Teaching Strategies	4
8.	Outcomes of Science Education: Scientific Temper, Attitudes, Skills and Interests	8
9.	Correlates of Achievement in Science	7
10.	Educational Technology	3
11.	Other studies of interest	8
	Total	61

Let us now refer to the research studies documented for the present survey. Javlekar, V.D. (1988) evaluated the effectiveness of exhibits of the Nehru Science Centre, Bombay within the context of scientific concepts to be developed among Class VIII students. He found that participatory museum displays convey scientific concepts more effectively than other methods, regardless of socio-economic status. Sivadasan, K.R. (1988) showed the relevance of science club activities for significant gains in composite performance when linked with the classroom teaching. Mitra, J. (1989) developed 10 modules in significant areas of human living for the benefit of not only elementary school-children but of school drop-outs too. Ghosh, A.M. (1990) went a step further by showing the relevance of non-formal science education by

Table 2

Frequency of Researches Conducted at Various Levels*

Sl. No.	*Level of Research*	*No. of Studies*
1.	M. Philosophy	5
2.	Doctor of Philosophy	34
3.	Research Papers	6
4.	Independent projects/studies	16
	Total	61

* If one excludes degree-bound research, the frequency falls to 22.

developing inexpensive resource materials on similar lines for the benefit of socially disadvantaged groups. Bhattacharya, S. (1990) also prepared a module on concepts in botany and general biology with a different orientation, that is, developing the investigative competencies of teachers. As if those efforts were not sufficient, Vedamani, M.N. (1988) in a major study developed and tested models of environmental education in botany relevant to the needs of socially disadvantaged groups of children studying in the schools of Kerala. These suggested models are worthy of consideration in other school subjects, and elsewhere, too. Let us now digress a bit.

Studies by Durani, P.K. and Sharma, A.L.N. (1981); Durani, P.K. (1988) and Lehari, G.K. (1988) focus on the content aspect of environment at the advanced level. These studies relate to "know thy life between tide marks", "Aquatic system in Orissa", and "Life in fresh water", respectively. Such studies, when conducted on a large scale, are surely going to challenge as well as stir the imagination of a large number of science teachers and students. The results of such studies can be described in teacher guides and student booklets (Lehari, G.K. 1988). We can then set up independent centres of learning for wider participation by other science teachers and science students at little extra expense.

Science Curriculum, Syllabus and Textbooks

There is a distinct difference in terminology when one talks of curriculum, syllabus and textbooks. All the three can be developed and evaluated continuously for relevance. Historically speaking, radical reforms in science curricula as already referred to, appeared in science teaching and education in the post-*Sputnik* era. Hardly any country of significance in the English-speaking world escaped their influence in one way or another. India was also no exception. This is a long story which is told elsewhere (Vaidya, N., 1989). It was in 1950 that Kelkar for the first time developed a curriculum in general science for secondary schools. Later on, other studies appeared with different approaches in mind. These approaches were by Vaidya, N. (concept-based plus children inquiries about the environment); Bhartendu (discovery orientation, 1976); Pai (environment as the base for college students, 1981); (Ganguli, D. and Vashistha, U.C. 1991) and Ramesh (1984) (objective based curriculum); and finally, Vashishta, U.C. (1986) (Biology within the context of mechanistic and organismic viewpoints). Then appeared several studies of varying interest in the area of curriculum evaluation by Singh (Ganguli, D. and Vashistha, U.C. 1991); Krishnan, K. (1981); Goyal, K.M. (1982); Arora, S.K. (1986); and Khalwania, N.S. (1986). Menon, S.S. (1986) examined the science education system of Gujarat State from the viewpoint of "Science as inquiry". Earlier, Joshi, P.K. (Ganguli, D. and Vashistha, U.C. 1991) had developed an 'edit' code for evaluation of science textbooks. It was, later on, left to Hijam (Ganguli, D. and Vashistha, U.C. 1991) who showed several pitfalls in the implementation of the science curriculum. Taking an overall view of the past researches, it is safe to conclude that this area is still in the category of "unfinished business" (Ganguli, D. and Vashistha, U.C. 1991). Lastly, two projects on "Improvement of science education" and "Environmental orientation to school education" by the Department of Education, Ministry of

Human Resource Development, are at the NCERT Headquarters (Ganguli, D. and Vashistha, U.C. 1991).

What do the present studies under review say? According to Mohanty, S. (1988), the position of science teaching in the high schools of Cuttack city, Orissa, is highly deplorable. Sunder Rajan, S. (1988) pointed out that there is little to admire and be proud of in regard to the teaching of biology in Tamil Nadu. Begum, K.H. (1990) showed that more than three-fifths of the teachers found the content in the new syllabus not only quite new but also overloaded along with dictation of notes by them as the dominant method of teaching. Radhamony, P. (1988) carried out an interesting study on textbooks written in Malayalam, using lexical morphemic and syntactic analysis and thus assessed the relevance of this technique for the improvement of science education. In a rare study, Radhamonyamma (1980) evolved an effective model for the presentation of chemical ideas through the regional language "Malayalam" in Kerala. In the same State, Cherian, M.(1988) reported favourable attitudes towards the modernisation of chemistry despite the gap of a decade between the introduction of modern concept-based chemistry and the corresponding pedagogical approaches. After having developed an effective programme of health and habits, Deshmukh, A.L. (1991) pointed out that even such an effort had its own limitations. These were: (1) a loaded curriculum, (2) lack of physical amenities, and (3) failure to practice healthy habits later on. It is, therefore, safe to conclude that we have yet to go a long way in developing a sound curriculum theory which works gainfully in respect of pupil behaviours.

Learning and Models of Teaching in Science

How do children learn? How do children think? How do children solve problems? How to analyse the contents inside the heads of children? How is true causality attained? What is the difference between bright children and dull children? Does the difference amount to this that the latter forget before the examination and the former after the examination? (Vaidya, N. 1994.) How to approach the teaching of science from the psychological point of view when the content in science to be taught is limitless? How to teach science as a tool subject? What is the relevance of Gestalt psychology (insight and productive thought) in science teaching? Is it possible to accelerate learning within the context of developmental psychology (Jean Piaget in particular)? Are children showing their evolving structures of thought while they commit mistakes during problem-solving? Does the growth of logical thought progress/regress with age? Lastly, is the development of logical thought hierarchically determined? These are very difficult questions to answer. But part of the answers to these questions are available from the efforts made by the following researchers.

Grewal, A. (1988), engaged for a long time in Piagetian psychology, stressed the role of the process approach to science teaching. She developed, tested, and thereby validated, the efficacy of the self-learning process, using self-instructional process-based learning materials. Prakash, B. (1990) concretised the teaching of abstract concepts such as "gas laws" and "chemical equilibrium" within the context of Piagetian psychology. The point not to be missed is that such abstract concepts demand a lot of formal reasoning on the part of adolescent pupils. Saxena, S.P. (1988) reported significant gains favouring the experimental group while investigating the acquisition of chemical concepts, using the periodic table as the base. Mohapatra, J.K. (1989) went a step ahead by consolidating available literature on four dimensions to the teaching-learning of science. Mohan, R. (1991) suggested an effective instructional model for concept-based learning in science. Hopefully, it is worth testing as well. Raghavan, A. (1991) stressed the importance of concept-mapping in learning physical science.

He showed the relationship between concept-mapping and other variables such as achievement, cognitive ability and attitudes towards science. Vaidya, N. et al. (1991b) over a period of 10 years or so, determined and developed several schemes of thought in their educational settings. Using the individual mode of administering problems as well as carefully chosen samples of pupils duly matched on intelligence, age, grade and socio-economic status, (Vaidya, N. 1960) hinted at the existence of a "hump effect" where thought progresses, regresses and again progresses till concepts settle down finally in children's heads (Vaidya, N. 1960). Later on, Vaidya, N. (1994) tried to press into service two schemes of thought, namely, "combinatorial grouping" and "exclusion of variables" for enhancing achievement in science (Vaidya, N. 1960). Rao, S. (1988) saw the relevance of her exploratory studies in optimising learning science in different parts of the country. Srivastava, K.K. (1988) in another interesting study examined the impact of science teaching on the child's concept of physical causality. Srivastava, K.K.'s (1988) analysis of pupil explanations is quite revealing for the development of scientific thought during adolescence. Lastly, Malik, C.K. (1990) explored the possibility of training science teachers, using four distinct modes of presentation.

The studies documented above are in the right direction and need to be translated into varied educational practices for use. What is left are the strategies still talked of in research literature. These are: directed observations and inferences (Vaidya, N.); structure of student learning outcomes (Collis, K.F.); learning cycle and reasoning patterns (Robert Karplus); concept-mapping and the cartography of cognition; Epistemological (Gowin, Bob); and Piagetian models for promoting teaching-learning processes. Such approaches, further developed and tested for meaningful learning on a large scale, will surely go a long way in providing a quantum leap for improving the quality of learning in science in particular and education in general from the developmental point of view (Vaidya, N. 1960).

Studies on interaction analysis, micro-teaching and mini-teaching, etc. simply appear to be conspicuous by their absence in the studies under review, except the one by Singh, O.P. (1989) who identified certain skills in science teaching and their effectiveness within the context of creative ability. He showed that it is possible to modify teacher behaviour if creativity variable is brought into the picture in verbal and non-verbal interaction patterns. Instead, models of teaching have appeared on the scene (Joyce, B. and Weil, M. 1985). There are problems here. First, we do not have a worthwhile theory of teaching/instruction. Secondly, cross-links among the several models need to be brought out explicitly for further depth and reflection empirically. Thirdly, following a single model in day-to-day classroom teaching is simply a non-starter proposition. Lastly, it is a tough nut to crack when it comes to developing teaching plans that meet the requirements of both highly varied objectives and diverse content. Despite these difficulties, it is of course highly desirable to modify science-teacher behaviour in varied ways. Awasthi, V. (1989) developed a fruitful training strategy for science teaching, using the Concept Attainment Model. Aziz, T. (1990) examined the effectiveness of information-processing models in acquiring chemical concepts. Awasthi, V. (1989) further said that thinking can be taught if appropriate teaching strategies are used. Kayathri, U.S. (1989) showed the effectiveness of the Jerry Luces memory model in botany, and that, too, in a real school setting.

Teaching Strategies

It is difficult to answer the question: Which one of the strategies/methods of teaching is the most effective? In the past, researchers have used the observational approach, the practical method, the problem-solving approach, the project method, the environmental approach, a combination of methods, use of science kits as well as toys and motion pictures, and finally, the environmental approach in their individual studies. They then compared each of them with the traditional approach. No clear-cut answer became available because their own experimental approach/innovation invariably turned out to be the best. Here they appear to have forgotten what Rousseau said, "Nature first creates the material before it gives it a form." Or, the researchers themselves appear to suffer from the "Hawthorne" effect; that is, the effect of research on the researcher himself. To illustrate:

Aranha, J. (1988) showed the utility of mastery learning approach for slow learners. They gained in scores on final tests along with strong academic motivation and self-concept habits. Gurumurthy, C. (1990) found the guided-discovery approach superior to the instructed-performance one when it came to the development of cognitive abilities and practical skills. Goel, V.P. and Agbebi, E.A. (1990) reported that the acquisition of psychomotor skills favoured the group which followed the individual laboratory method rather than the lecture-demonstration method. Shishta, R. (1990) found that the treatment/intervention comprising the blended strategies of different modes of teaching given to the experimental group brought about significant differences in achievement in biology in comparison to the control group.

In sum, it appears difficult to give a verdict on the superiority of any method of teaching; for this long-term studies based on some sort of theory (say instruction) are required. Otherwise, it remains a matter of doubtful innovations or suspect temporary gains.

Outcomes of Science Education (Scientific temper, attitudes, skills and interests)

There are tangible as well as intangible outcomes of science teaching and education. Whereas the tangible outcomes of science education such as scientific knowledge and problem-solving are easy to measure with the help of paper-pencil tests, others resist measurement. The best tribute a disciple can pay to his master is to contradict his work. How do you measure that challenge too? Stating the components of the scientific temper or for that matter, scientific attitudes, is of course, necessary, but is not sufficient. What is required are their explicit manifestations in terms of stable and persistent behaviours in daily life. Here, even the behaviour of active scientists outside of their laboratories is as erratic as elsewhere in other sectors of social life. Finally, it is not difficult to find a correlation between two or more variables, say, the height of a person and his intelligence. Let us now review the studies.

Dubey, K.K. (1992) attempted to measure scientific temper and concluded that whereas all groups of students showed scientific temper, significant differences were observed between male and female science teachers. Mandlia, S.S. (1988) examined attitudes of secondary stage students towards their own science curriculum and its relationship with achievement motivation. Mandila, S.S. (1988) concluded that all students from urban and rural areas possessed favourable attitudes towards the science curriculum. Effective academic programmes, according to him, also develop favourable attitudes towards the science curriculum. Ghosh, S. (1989) showed that whereas scientific aptitude was related to scientific attitude, there were no such significant differences in respect of sex, socio-economic status and place of work among the various groups. Kumar, U.S. (1991) showed that the development of scientific attitudes depended upon their perception of science teaching and nature of learning experiences. Nellaippan, N.O. (1992) went a step further by studying both attitude and interest within the context of the learning environment and showed that the various components of the learning environment are significantly related to both scientific attitudes and interests. His study reveals another surprising finding that sex and locality of the students do not influence their scientific attitude and scientific interests. Malviya, D.S. (1991) examined attitude towards science and interest in science. The study showed that high scores on attitudes towards science favour higher scientific interest. Further, with minor differences here and there, age, sex, profession and socio-economic status have no effect on attitudes towards science. How lucky would have been our country had such findings been true! Let us now digress a bit while referring to two more studies.

Sood, J.K. (1992) and his students at the Regional College of Education, Ajmer (Rajasthan) have studied attitude towards science and scientists among students and teachers for years. These are very valuable studies which need to be consolidated at one place. In the present major project, he examined a rare and valuable problem, "The Public Understanding of Science", using his own tests, among students and members of the public. His study revealed significant relationships between the public understanding of science and attitudes towards science. However, sex differences on public understanding of science and attitudes towards science also appeared significantly in this study. Sharma, M.K. (1990) studied scientific literacy, attitudes towards science and personality tracts of students and teachers. His findings too received support from the large study by Sood, J.K. (1992). It is suggested that the conflicting findings as reported in these studies may be treated as hypotheses for further testing on known groups of students, teachers and members of the general public with a view to bring out the limitations of paper and pencil tests as well as the value and significance of the so-called 'theoretical mean'. Further, the factor of desirability, that is, always giving the best response, may be further looked into.

Correlates of Achievement in Science

Our examination system, as we knew it, is currently in shambles. For the last forty years or so, we made serious efforts to reform it. The more we reformed it, the worse it became. It is known that at every grade/stage, there is lot of failure in our schools. As if these were not sufficient, there is lot of continuing unabated cheating by the students. Still worse, teachers are afraid of taking up supervisory duties because of nearly fatal threats issued by students and certain goons of influence enjoying political clout in our society. If this situation persists, we will continue to have examinations under firm police cover plus insurance benefits for the supervisory staff. Sooner or later, the very examination centres may be sold for obtaining chronic success. Lastly, failure in examinations not only degrades young people in the eyes of their parents but also socially in the neighborhood, and finally, in the society at large. Leaving apart this broad context and situation, a few studies are reviewed for this survey. Otherwise, abundant literature in this area is available. Alexander, B. (1990), studied the influence of critical thinking, science aptitude and socio-economic status on achievement in science. Alexander, B. (1990) showed that whereas sex differences in achievement existed, all the three variables contributed significantly to achievement in science. Sharma, A. (1989) studied the role of personal and social factors affecting the success and retention of girls in science and showed that achievement was not at all a function of role models as conveniently understood. Rao, D.B. (1990) aimed at determining the relationships among scientific attitudes, scientific aptitude and achievement in biology which were finally found by them to be significantly related to each other. Kar, D.K. (1990) found a significant relationship between attitude and achievement in general science. Phalachandra, B. (1989) found a positive relationship between concept-based achievement in chemistry and environment. Sex differences in achievement favouring boys existed. Parents' qualifications, sex and place of birth (urban areas) contribute substantially to achievement. Darchingpuii (1989) confirmed Kar, D.K. in principle and added socio-economic status, type of school attended, family facility (opportunity structure), scientific attitude; and finally, that problem-solving favoured achievement in science. However, there is a need to attend to the special needs of girls. Finally, Joshi, P.K.

(1989) found that all the five aspects of school characteristics contributed significantly to the acquisition of concepts in chemistry.

What factors, therefore, can possibly contribute to success in examinations? These are: home background, type of school attended, strong background in mathematics and physical sciences in particular, early specialisation, interaction between students and parents and teachers, homework, opportunity to learn, and personal library. Lastly, what turns the scales in favour of the students are their own personal efforts, energies, persistence and the "will to succeed" in the face of impending failure.

Educational Technology

Science and technology have become the growing judges of our society, theoretically speaking homes and schools, being no exception. Now it is as well the age of computers which can be employed in teaching science. It is a long exercise which could always remain open to scrutiny through hypotheses setting and testing philosophy. In this context, Bhattacharya, M. (1989) made a critical review on the use of the computer as an instructional aid for teaching chemistry and found that the available softwares (of course, not covering the whole syllabus) were of good quality. Sahni, R. (1991) studied cognitive and non-cognitive factors leading to success in the subject of computer science as taught in the senior secondary schools of Delhi. Sahni, R. (1991) pointed out the scarcity of qualified computer teachers in schools. Malik, A.K. (1992) found increased productivity when the apex institute introduces and manages computerisation. Extensive studies are, however, needed in this area. Otherwise, it may not happen that one type of rigidity is replaced by another.

Other Studies of Interest

Science Laboratories

These are our most precious educational resources. Rao, K.N. and Gupta, M.K. (1990) surveyed science laboratories in the states of Maharashtra and Rajasthan. Whereas the overall situation in this regard is quite favourable both in rural and urban schools in both the states, it is not known how the facilities are in fact used. It is only in Rajasthan that the majority of the students perform their experiments individually. Further, it is only in this state that government schools have facilities for improvising and repairing scientific equipment. Malhotra, V.K. (1988), on the other hand, evaluated critically the existing facilities for different types of schools in Delhi. The three types of schools (public, government and central), differed significantly in respect of existing facilities for science-based curricular and co-curricular activities, supervision of theory classes as well as faculty meetings/conferences and welfare of teachers and students. Ekpo, J. (1991) found poor awareness of laboratory safety in Nigeria despite such facilities being available there. Pandit, B.L. (1989) identified eight major laboratory skills in chemistry in their hierarchical order. The study revealed a significant relationship between the ability to learn content in chemistry and the ability to acquire cognitive and manipulative skills. It is necessary to make a comment here. There is a widespread impression that our laboratory work takes place in a sealed tube. Students only verify what is already known. They hardly make use of their talents and tools in their laboratory work. The question then arises: what kind of laboratory skills develop and are tested in practical examinations, later on? A major reform is needed here despite the fact that we have improved science teaching facilities all over the country.

Scientific Aptitude and Creativity

Studies in this area also appear to have gone out of fashion. Historically speaking, the factor of creativity appeared after studies on the structure of intelligence, using factor analysis, failed to explain some small extra variance in scores after the emergency of aptitude factors. Srivastava, M.

(1988) probed into the science aptitude of higher secondary school science students in relation to their cognitive styles. She found significant sex differences in "dogmatism" only. Srivastava, V. (1992) examined creativity among higher secondary students in relation to scientific aptitude and attitudes towards science. Whereas the study showed a relationship between scientific aptitudes and creativity, at the same time significant sex differences in aptitude, creativity and attitudes towards science existed in her study.

Questioning Ability of Students

It is said on the basis of studies in interaction analysis that the teacher talks too much in the classroom. In this interesting study, Kumar, M.S.G. (1991) studied the effect of intelligence, achievement (biology) and extraversion on the questioning ability of Class IX pupils. Kumar, M.S.G. (1991) found that intelligence, achievement in biology and extraversion influenced the number and level of questions asked.

Science Education Abroad

Makkar, G.L. (1991) in his research note made some observations regarding education and scientific research in Japan. Here, lengthy reviews in historical perspective are urgently required for drawing appropriate lessons for our country.

Research Frontiers in Science Education

Let us look back at what we have achieved and what is left undone. Not to do so at the end of the journey is to court mediocrity! Whatever exists needs to be recognised, admired and admitted. Whatever is left is a chance to the futuristic researcher in science education and others to capture and accomplish at an early hour. It is pretty difficult to hazard guesses and, therefore, some key statements are given below which tell not only the road to be traversed but also the kind of road too.

1. There is hardly any academic interest in the philosophy of science (scientific methods included) as well as the nature of science. Moreover, there is hardly any interest in philosophical research when it comes to the formulation of productive problems for educational research in science.

2. There is hardly any professional interest in the history of science/historical episodes for making parts of the curriculum in science lively and exciting to the children.

3. There is hardly any professional interest in knowing the position of science teaching in the country and elsewhere as well as in the States, except two critical reviews—by Vaidya, N. (1989) and Sharma, H.L. (1989). There is hardly any professional interest in carrying out policy studies in science education.

4. It is very necessary to pick up key as well as side findings of interest not only within a particular area but also across various areas of science education. Here, such findings from other school subjects as well as sectors of education can also be considered. Having done so, it is again very necessary to develop a "zone of proximal development" or "active museum of assets" for applying this set of findings with a view to improve the entire climate of the school. For example," the teacher need not talk too much in the classroom" is an appropriate proposition to work out in highly varied contexts across the entire school curriculum.

5. Home influences and school influences do effect pupil achievement. How? These need to be studied in different educational settings on a country-wide scale.

6. It is possible to develop as well as enhance the problem-solving capacities of individual schools. Why ? It is so because it is possible to improve schools in every conceivable manner. Even teachers and students are in a position to contribute to the growth of the school covertly as well as overtly.

7. The psycho-statistic paradigm, of course, highly desirable, is not sufficient. It may contribute a little to the development of a theory.

When it comes to equivalent intervention/ treatment, the teacher is more like a gardener than a farmer. Hence, decision-making is necessary—whether to accept or reject, say, a given innovation at a particular level of confidence.

8. It is very necessary to visualise a very broad framework of research in science education. It is then possible to pick up research problems for investigation on a large scale, using cross-sectional as well as longitudinal studies which are conspicuous by their absence in our country. Through cooperative research, parts of this main problem can be tackled. Execution of independent studies as well as projects within the wider scope, thus, are our best bet in this direction.

9. It is very necessary to study outside variables in their widest variations, for example, intelligence, achievement and socio-economic status. Until and unless there are special reasons, it is not necessary to develop tools of doubtful reliability and validity for every investigation. A tool improves itself in its operation and makes comparison of findings easy to interpret. Secondly, psychometric tests are very powerful tests. The results so received be further evaluated in the context of desirability of goals and decision-making as already suggested.

10. It is very necessary to handle conflicting findings. These need to be reconciled in a manner deemed feasible. For example, it is difficult to reconcile the findings in learning theory of psychologists such as B.F. Skinner, R.M.Gagne, Max Wertheimer, Jean Piaget, J.S. Bruner and L.S. Vygotsky. So a given unit of instruction/models maybe approached in diverse ways. The same applies to the models of teaching for modifying teacher behaviour. Let us remember that research is not a single-shot affair at all.

11. A curriculum is a very broad framework but a syllabus is not so. It is very difficult for a single worker to evaluate a curriculum or for that matter, syllabus too. It is a problem to be accomplished by experts, (who are in short supply at the moment) at the instance of national agencies/State agencies/Boards of Secondary Education. We have also listed factors which contribute to success in examinations in science. But how they operate in actual school settings is not known.The students' view of curriculum and evaluation is also to be taken seriously. Lastly, more studies are needed on the acquisition of scientific skills and interests, an area of work which is very close to the lives of children.

12. It is very necessary to throw a bridge between an experimental project and a developmental project. The observation is equally applicable to some of the independent projects reviewed. For example, a module is developed which is not used and tested for classroom relevance. Why? The said project is over. Or it is then concluded by desirable statements which lead no one anywhere.

13. There is a subtle difference between professional commitment and professional judgment. Given the situation today, it is possible to develop the latter by furnishing science teachers' minds through appropriate exposures of varying directions. Personal readings, professional interactions, and reflection thereafter, are the other 'must' for science teachers and educators. Let it be said frankly that education is easy to grasp if not understood. For example, the so-called basic principles of teaching, for example, "teach from the concrete to the abstract", hardly clarify anything of educational value. It is precisely for this reason that superficial understandings picked up from here and there need critical scrutiny as well as testing for meaningful classroom learning. Hence, there is distinct difference between the raw recruit and the developed professional.

14. It is not denied that we have no difficulties in promoting research in science education. First, research in science teaching is not at all a rewarding career. Secondly, the number of active research workers in this area is too small. Thirdly, our science teachers are not in the habit of reading professional journals, even those

which cost as little as a cup of coffee, for example, *School Science* (NCERT). Finally, we think that a problem is solved if it is just talked of. We do not have an experimental attitude towards educational problems. So we do not know "where" and even "how to stitch"? metamorphically speaking, our part problems and solutions in science education. So, a stitch out of time creates problems for nine.

Taking an overall view, our problems in education are gigantic. About half our population is illiterate. There are then the problems of the handicapped, the underprivileged and education of girls, especially those in rural areas. The whole situation is like mouldy, if not fully rotten, bread. We have to find our own "penicillins" by breaking up our problems at their joints in the phraseology of Plato. The hammer must fall sooner or later on the anvil, thus giving the whole nation an Indian Tradition of Science Teaching. So it is a problem for all: researchers, administrators, science teachers, and students, too. They should learn to master the stimuli rather than the responses. It is also highly desirable to draw appropriate lessons from international experiences for our benefit. Until then, the following message is clear:

It is time to dream, time to visualise, time to act, time to know, time to accept and reject, time to remember and time to reach the infinite by developing the scientific and technical capabilities of our children, an entirely new race to be run for winning new posts in education in the next century.

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