Research Review Article

Research in Science Education in India

R.R. Koireng*

Abstract

Realising the importance of improving the practice of teaching-learning of science in schools, science education has, in recent years, emerged as an independent field of research. The paper reviews science education research, conducted after 2000 related to the issues and concerns of teaching and learning of science in Indian schools. It includes research reports, research journals and articles. In order to provide good science education to children, it is important to understand the nature of science, the way contents are organised and presented, the pedagogy adopted, textbooks and other teaching-learning materials, the assessment and evaluation scheme adopted, and so on. All these require an in-depth research to unravel the best practices to be adopted. The present review of research in science education is broadly classified into seven areas, namely—curriculum and teaching-learning resources, cognitive studies, science teaching and learning, creativity, gender issues, achievement in science, and environmental concerns. The essence of researches in each area is given, including the trends and suggestions for further research. The understanding of various issues in science education through these researches will provide insights in improving the science curriculum, teaching-learning materials and pedagogical practices to be followed in teaching science.

सारांश

हाल के वर्षों में विद्यालयों में विज्ञान के शिक्षण-अधिगम के अभ्यास में सुधार के महत्व को समझते हुए विज्ञान शिक्षा अनुसंधान के एक स्वतंत्र क्षेत्र के रूप में उभरा है। यह शोध समीक्षा 2000 के बाद के वर्षों में भारतीय विद्यालयों में विज्ञान के शिक्षण और अधिगम संबंधित मुद्दों

* *Associate Professor*, Curriculum Group, NCERT, New Delhi-110016 (e-mail: karenkrr@gmail.com).

और सरोकारों पर किये गए विज्ञान शिक्षा अनुसंधान की समीक्षा करता है। इसमें शोध रिपोर्ट, शोध पत्रिका में प्रकाशित शोध पत्रों को सम्मिलित किया गया है। बच्चों को अच्छी विज्ञान शिक्षा प्रदान करने के लिए विज्ञान की प्रकृति, विषय-वस्तु को व्यवस्थित और प्रस्तुत करने के तरीकों, शिक्षण विधियों के उपयोग, पाठ्यपुस्तकें और अन्य शिक्षण-सामग्री, मूल्यांकन और मूल्य-निर्धारण योजना का ज्ञान आवश्यक है। वर्तमान समीक्षा में विज्ञान शिक्षा से संबंधित सात क्षेत्रों को शामिल किया गया है: पाठ्यचर्या और शिक्षण अधिगम संसाधन, संज्ञानात्मक अध्ययन, विज्ञान शिक्षण और अधिगम, सर्जनात्मकता, लिंग संबंधी मुद्दे, विज्ञान में उपलब्धि और पर्यावरण संबंधी सरोकार। प्रत्येक क्षेत्र में अनुसंधान का सार दिया गया है, जिसमें भविष्य में अनुसंधान के लिए सुझाव सम्मिलित हैं। यह समीक्षा विज्ञान शिक्षा में विभिन्न मुद्दों की समझ, विज्ञान के पाठ्यक्रम में सुधार, शिक्षण- सामग्री और विज्ञान शिक्षण में पालन किए जाने वाले शिक्षा-शास्त्रीय विधियों में सुधार पर बल देता है।

Introduction

Humans are by nature curious and inquisitive. This curiosity and inquisitiveness have driven them since time immemorial to explore the 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 relationships, make and use new tools to interact with nature, and build conceptual models to understand the world. This human endeavour is called science. Broadly speaking, the scientific method 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 natural world. 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.

Science is a dynamic, expanding body of knowledge, covering ever-new domains of experience. In a progressive forward looking society, science can play a truly liberating role, helping people escape from the vicious cycle of poverty, ignorance and superstition (*NCF, 2005*).The advances in science and technology have transformed traditional fields of work such as agriculture and industry, and led to the emergence of wholly new fields for engagement. People today are living in a fast-changing world where the most important skills are flexibility, innovation and creativity. These different imperatives have to be kept in mind in shaping science education.

Nature of Science Education

About six decades ago science education came to be recognised around the world as an independent field of research. The concerns of research in science education are distinct from the concerns of sciences and those of general education. Its methods and techniques were initially borrowed from the sciences but now new methods are being developed which are well suited to the research questions. Motivation for this research comes from the need to improve the practice of teaching science. We begin by asking which methods of teaching work better than others? Studies in the 1970s typically compared experimental classrooms with control groups. New teaching aids were tried out; lecture method was 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; teachers and students in the classrooms too vary widely. Teaching and learning is a complex, context-dependent process and one needs to first describe this complexity in order to understand it, before eventually aiming to control it (Berliner, 2002). The aim of teaching science includes not only to acquire scientific facts and phenomenon involved but also to imbibe scientific temper and certain scientific values such as honesty, scientific attitude, integrity, cooperation, concern for life, preservation of environment, and so forth. Activities and experiments are the hallmark of science and they are also essential for science learning. The Hoshangabad Science Teaching Programme (HSTP) of 1970s, an initiative of the state of Madhya Pradesh, is an example of intervention in science teaching at micro level. The District Primary Education Programme (DPEP), the *Sarva Shiksha Abhiyan* (SSA) and the *Rashtriya Madhyamik Shiksha Abhiyan* (RMSA) also form a part of science teaching intervention at the macro level in schools of the country. These interventions had a varying impact on science education in the country.

Understanding the dynamics and diversity of classroom in the country gives us an insight into how science ought to be taught. Good science education requires not only a good teaching learning material, but also innovations to create interest in the learners. However, to begin with good learning materials will help the teachers and students in enabling them to learn science. Eventually, it is the teachers who negotiate the teaching-learning process in the actual classroom. The ability of students to learn meaningfully the intended skills, values and attitudes depends upon the teaching strategies adopted by the teacher. Teacher is a very important component of science education that has deep influence on student's learning of the subject. Often misconceptions of the teachers are inadvertently transferred to the students. Though efforts are being made to teach science following the method of enquiry and hands on experience, it is of common sight in most of the schools that science teaching continues to be dominated by chalk and talk method. Sometimes it tends to be driven by examination system prevailing in the country and, in fact, more often than not teaching is influenced by the typology of the questions asked in the examination. This is more in Classes X and XII because of the board examinations in which the students have to appear.

To meaningfully teach science to children, it is imperative to know the nature of science, the way contents are organised, the teaching strategies adopted, resources and other teaching-learning materials required, the evaluation scheme adopted, and so on. All these requires an in-depth research to unravel the best practices to be adopted. Interest in science develops quite early in life (Gardner, 1975). The decline in interest in science in later years of studentship can be addressed to a certain extent by providing all the factors conducive to the development in science from early years itself.

Against this backdrop, this chapter reviews science education research, conducted during 2000–2015, related to the issues and concerns of teaching and learning of science in Indian schools. While doing so, attempts have been made to identify gaps in research in the field of science education that need urgent attention.

Past Surveys of the Research

The earlier reviews of research in education carried a chapter on science education in the fourth (Ganguli and Vashishtha, 1991), fifth (Vaidya, 1997), and sixth (Chunawala, 2006) surveys. The fourth survey of research in education covered researches conducted during 1983–1988, fifth survey during 1989–1992, and sixth survey during 1993–2000. The number of researches reported in fourth, fifth, and sixth surveys were 56, 61 and 120, respectively. The sources covered in the sixth survey were primarily *Indian Educational Abstracts, International Journal of Science*

Education, Journal of Research in Science Teaching and Journal of Education and Social Change. The researches were related to the following areas— Cognitive studies, science teaching, teaching materials, attitude and science, gender issues in science education, creativity, achievement in science, and environmental factors. The sixth survey highlighted the need to do more research in the field of history of science, philosophy of science and sociology of science, which are deeply intertwined, and also in science curriculum that would present not only science but also its very methodology as evolving with time. There is a need to develop curricula and teaching materials with these perspectives in mind.

The Present Survey

The present survey attempts to consolidate science education research conducted at the school level in the Indian context after 2000. Based upon the availability of researches, the chapter is divided into the following sub-sections— Curriculum and Curricular Materials, Cognitive Studies, Science Teaching and Learning, Creativity, Gender Issues, Achievement in Science, Environmental Concerns, and The Way Forward.

Curriculum and Curricular Materials

Curriculum is one of the most important areas of science education as it guides the entire process of teaching-learning. The science curriculum at the school level in India has undergone several changes in the past few decades both in terms of content and approach. Studies have been conducted to examine science curriculum, syllabus and teaching-learning resources including textbooks. This section examines studies pertaining to curriculum, teaching-learning materials including textbooks and teaching aids.

Curriculum

Scholars have conducted studies related to different aspects of science curriculum including the objectives and philosophy of science curriculum development. Ediger (2000) examined various parameters including organisation of science curriculum, assessing student achievement, philosophy/psychology of education for evaluating and designing science curriculum. The researcher (Ediger, 2013a) further examined philosophies of education which might provide guidance in developing science curriculum. Kulkarni (2013) studied a number of concerns related to curriculum development in science and mathematics, in terms of the explicitly declared national goals and objectives such as providing equality of educational opportunity, improving rural schools, values in education, introduction of vocational stream, utilising field-tested methodologies, etc. These have implications for school curriculum, school infrastructure, teaching materials and teaching strategies. Awasthi (2000) highlighted the present educational scenario of the country and discussed the issue of relevance in great details. He proposed a number of suggestions for the development of school curriculum based on practices followed the world over and keeping in view the needs of the Indian society, its rich cultural heritage and inherent unity in diversity. The need for incorporation of value education in science teaching (Kishore, 2000) and restructuring of science instruction in the light of understanding gained in the nature of science (Sood & Saraswat, 2011) has also been reported.

Science education is dependent on context. This section contains studies concerning students' knowledge about selection and organisation of content in the Indian context. The study by Mehrotra and Banimal (2006), conducted in primary schools run by the Delhi government, reported that children coming from an agricultural background carry with them rich procedural knowledge about animals and plants, raised and grown in the farms. They suggested that while framing a curriculum for biology instruction, the cultural perspectives may be kept in mind. Another study (Gafoor and Narayan, 2010) conducted on upper primary students of Kozhikode district in Kerala found that out of school science experiences contributed to interest in science. It was further observed that the influence of experience on interest was more in biology than in physics and chemistry. The study advocated the need to take cognizance of these facts while preparing curriculum, teaching-learning materials and teaching strategies. Similar results for secondary students of Kozhikode district have also been reported (Gafoor and Jaithra, 2012).

Singh (2013) identified three important features of physics curriculum for rural teachers in terms of content, method and values of physics that constitute the scientific temper. Jain (2000) examined biology curriculum and found the need to incorporate developments in biotechnology and medicine, as well as concerns for the environment and survival of life. Similar concerns for incorporating disaster management (Kaur, 2010), nanoscience (Ravichandran and Sasikala, 2010), and agriculture (Sacheti and Mehrotra, 2000) in school curriculum have been expressed.

Thus, there is a growing concern to frame science curriculum taking into consideration the needs of the society, the experiences and context of the learners, etc. There is also a strong view among researchers to include new and emerging areas of science such as biotechnology, nanoscience, disaster management, agriculture, etc., in the science curriculum.

Curricular Materials

Research shows that though textbook is only one of the diverse teaching-learning materials for curriculum transaction, for the majority of school going students and their teachers, it is the only accessible and affordable curriculum resource. For example, Agarkar and Deshmukh (2002) studied the opinion of a large number of teachers teaching at the upper primary stage in Ashram schools, and found that textbook is the most important instructional material used in school teaching. They also reported that the content and style of textbook influenced learning of the subject and recommended that textbook should be modified suitably to facilitate learning of science among Ashram school students. Gangoli (2000) examined the important role of textbooks in curriculum transaction and found that the content of the text, its structure, method of presentation and the role of the teacher, etc., influenced the usefulness of the book and suggested an open-ended approach of developing textual materials. Parida and Goswami (2000) examined NCERT Class IX science textbook regarding analogies included in it and noted that at some places students are likely to develop misconceptions due to inadequate analogical explanation (AE).

Bansal (2014) examined the middle class science textbooks of NCERT and Eklavya for the ways in which they support scientific enquiry. The finding suggested that contextualising science by means of inquiry based textbooks would strengthen the bonds between science, society and develop critical inquiring minds. Das (2012) studied the effectiveness of self study materials for teaching general science vis-a-vis the traditional method adopted for teaching general science to Class IX students. The performance of the students taught through the developed self study materials was significantly higher than those taught through the traditional method. Hence, there is a consensus among researchers that textbook influences the method of teaching adopted by the teachers. The reviews also indicate the need for contextualisation of science content as per the context of students.

The findings of the research studies show that the basic facilities for teaching science such as laboratory, laboratory items and equipments are still lacking in schools. There is also concern regarding the utilisation of laboratory equipments among teachers in teaching-learning process. For example, Singh (2006) conducted an assessment of the existing facilities available in the high schools of Chimtuipui district of Mizoram. A total of 60 teachers (51 males and 6 females) from 40 different high schools of the district were included in the study. The findings revealed— (a) lack of qualified teachers in all types of school (b) lack of library, laboratory, equipment and chemicals, audio visual, acids, etc., and teachers were mainly using the translation method in the teaching of science. Another study (Sharma and Patel, 2006), conducted in 30 government SC or ST schools in Madhya Pradesh and 30 Jawahar Navodaya Vidyalayas (JNVs), reported the non availability of science laboratory at secondary level in SC or ST schools as compared to JNVs schools. The usage and effectiveness of science laboratory was found average in JNVs and below average in SC or ST schools. In another study (Ajitha and Pushpam, 2000), it was found that though most of the teachers agreed on the importance of teaching aids, yet few used it during teaching-learning process. Mohanty (2012), in a study conducted on biological science curriculum in Odisha secondary schools, reported many shortfalls like absence of laboratory in almost all the schools, textbooks with deficiencies, lack of appropriate and adequate teaching aids, non performance of co-scholastic activities, absence of access to community resources, lack of initiative to visit places of biological and scientific importance in order to connect knowledge to life outside the school and to make learning more practical rather than textbook centric.

Cognitive Studies

Cognitive studies in science refer to the studies concerned with learning of science. Cognitive research aims at developing a 'science of science learning'. Research studies in this category include understanding of science, misconceptions or alternative conceptions in science and cognition. This (cognitive studies) is a major area for research in science education. Researchers have examined the level of understanding of science and misconceptions or alternative conceptions held by the students and teachers.

Understanding of the Science

Difficulties in understanding science concepts, as well as organisation of content vis-a-vis cognitive level of the child have been examined. Haydock (2011) reported that a lot of problems were faced by teachers like work overload, too many duties, inadequate pay, etc. Other than these problems, science teachers complained about syllabus being difficult and vast, textbooks having mistakes, students not interested and science concepts not related to the students' lives. The study suggested about the lack of understanding concerning nature of science due to which science is actually not taught to students. Kala and Ramadas (2001) examined Piaget theory and reported that the Piaget's influence led to a shift from behaviourism to constructivism. They observed that developments in cognitive science too contributed to the research paradigms and methods, and the philosophy of perception and representation might guide research while work in the tradition of situated cognition might hold promise for a philosophy of praxis and action. Pant (2006) observed that the traditional definition of science as a systematically organised body of knowledge has been expanded to incorporate the processes and procedures of science. The processes of science emphasise science as a way of observing, thinking, creativity, investigating accurately and truthfully rather than adopting conformist orientation. The study (Pant, 2006) recommended proper sampling and representation of the contents in the textbooks and the relevance of the analysis of textbooks for enhancing the quality of science textbooks.

The metacognitive knowledge of strategy, task and personal variables enable students to perform better and learn more (Rajkumar, 2010). Padhi (2013) examined the relationship between cognitive preference style (CPS) and academic self concept in science (ASCSc) among secondary school students (200 students—102 boys and 98 girls from Class IX in four schools of Bhopal). Cognitive preference style of both high and low ASCSc groups of students was found to be same. Use of application was associated positively with ASCSc. Memory was negatively and significantly correlated with ASCSc and the relationship of questioning with ASCSc was found to be low.

Gupta (2000) in the paper titled, 'A Constructivist Enquiry Learning Model for Science Education' reported that psychological and social constructivist perspectives are supported by neurocognitive evidences where learning is both biologically and socially mediated. Three sources of knowledge, i.e, spontaneous, formal and creative are integrated through self exploratory, collaborative, novel and technologically embedded experiences for developing multiple intellectual abilities like cognitive, creative and affective. The role of the teacher is envisaged both as an instructor and a facilitator matching the pedagogies with how students learn as opposed to purely didactic or absolutely getting out of the way of the students. Another study (Pal, 2000) found that the idea children hold through daily experiences about various concepts bring with them into classroom, which shapes the construction of the scientific knowledge in a particular way and this affects the methodology of science. Prabha (2010) reported various approaches to teaching-learning process in order to make students inquisitive thinkers, who question, reflect, reason, make association with prior learning, imagine and think.

Saminathan and Mohan (2002), based on their study on 10 low scoring students in physics in quarterly examination in government higher secondary school, Ariyankudi, reported the need for student counselling which can sensitise the individuals to their potential to determine what they would like to be. It helps the pupils to understand and classify their views of life space, and to learn to reach their self-determined goals through meaningful, well-informed choices and through resolution of problems of an emotional or interpersonal nature. They further reported that various cognitive factors like intelligence, creativity and memory, and other social factors like age, sex, social background also influence the students learning at different stages. The research thus shows that understanding the nature of science, process and procedure of science and the daily life experiences influence learning of science.

Misconceptions or Alternative Conceptions

Studies have examined misconceptions or alternative conceptions held by the students and teachers in different subject areas. Singh (2000) identified errors or misconceptions in physics at senior secondary level, such as electric line of forces, electric field, microscope and telescope, eye lens and objective lens, etc. It was reported that the causes of large number of failures or misconceptions were wide ranging beginning from poor teaching to unreliable evaluation procedures. He further mentioned that the need of the hour was to strengthen teaching in schools and develop an evaluation system which is flexible, reliable and student-friendly. In a study conducted on a stratified sample of 627 pupils studying in Class IX in a district of Kerala, Gafoor and Akhilesh (2008) found that 42 per cent of high school students had misconception regarding majority of concepts in physics. About three-fourth of the sample exhibited misconceptions with the concepts of density, sound, work and gravity. Gender and rural-urban differences were reported. The study also suggested steps to remove the misconceptions. In another study (Sindhu and Sharma, 2000) conducted on 68 senior secondary students in Bhopal, it was found that students committed errors in naming coordination compound and in some other cases students developed misconceptions about the rules for naming coordination compound. Arora, Mahapatra and Parida (2010) identified episodic conceptualisation in the minds of pupils in the domain of interaction of the concepts 'kinetic energy and work'. Teaching strategies were suggested to reduce episodic conceptualisation such as emphasising on the interchangeability of 'kinetic energy and work' concept and designing activities to demonstrate the interchangeability of 'kinetic energy and work'.

According to Kishore (2002), lecturing and rote-learning lead to misconceptions in Physics. Parida, Mahapatra and Goswami (2000) examined secondary level learners' ideas about the inter-relationships between various concepts related to gravitation as well as their misconceptions. On the basis of their study on a sample of 93 students of Class IX and 166 students of Class X from two CBSE affiliated schools in Bhubaneswar, the researchers identified a number of misconceptions held by students related to gravitation, such as, 'Earth pulls objects towards its centre, moon does not pull objects towards its centre' and 'the gravitational force is constant throughout the universe'. The findings have implications on teacher, curriculum framers and textbook writers. Gupta and Ravichandran (2001) reported the performance and types of mistakes Class XI students commit in various concepts in Chemistry based upon knowledge, understanding and application of concepts. Sharma (2007) listed a number of common misconceptions concerning the topic of force among students across different levels. Some of the misconception reported about force were—(a) force continues to be associated with the body till it remains in motion (b) velocity and acceleration are inseparable physical quantities and are in the same direction (c) force is in the direction of velocity, etc.

A few studies have been carried out concerning teachers' misconceptions. Jain (2011) studied the misconception held by experienced teachers regarding simple harmonic motion (SHM) and reported several misconceptions held by the teachers pertaining to sign for displacement, velocity, and acceleration, its effect on speed during different time intervals and direction of acceleration. The strategies for transacting this concept were also reported. Similar study by Goswami and Parida (2004) revealed misconceptions held by PGT physics teachers on simple harmonic motion topic. Pachaury (2000) reported the anomalous performance of teachers on logical/spatial and coordination of perspective tasks. The study was conducted on 29 Biology/ Chemistry post-graduate teachers from 10 States and UTs. These teachers were in the age group of 27 to 35 years and had teaching experience of 2 to 7 years. Another study (Saxena, 2001) examined the existence of large number of misconceptions among the teachers related to physics teaching at senior secondary level in different parts of India. Sharma and Sharma (2003) reported an overwhelming number of teachers carrying many misconceptions about basic concepts of physical optics despite the fact that teachers were well qualified and had teaching experience of many years. The study was conducted on a group of 21 Physics PGTs of senior secondary school of repute having an average teaching experience of about 12 years.

Jadhao (2002) highlighted some of the common misconceptions prevailing amongst students as well as teachers concerning some basic concepts of light in the paper, 'Teaching of light up to secondary level'. Some relevant contents for teachers were provided to tackle this. Agarwal (2012) reported that lack of adequate thinking and visualisation leads to misconceptions or alternative conceptions not only in the minds of the students but also in the minds of the teachers. Some important aspects of motion in two and three dimensions vis–a–vis one dimension have been discussed to improve thinking and visualisation. Sharma and Singhai (2000) found a cognitive conflict in the minds of children in 12–14 years age group in physics. It was also found that the practicing teachers have very little knowledge or right kind of knowledge to solve such cognitive conflict in the mind of their student. The study adopted questionnaires and interview technique for collecting data among students in the age group of 12–14 years, practising teachers, prospective teachers, teacher educators and college teachers.

The review reveals that students and teachers have misconceptions related to many concepts of science. It also identified the poor teaching, rote learning and faulty evaluation practices followed as the main reason for misconception in students. Suggestions for improving misconceptions held in various concepts of science are also suggested, such as improving teaching-learning process, adopting flexible student-friendly evaluation procedure. These researches have varying implications on improving teaching practices, textbooks, evaluation procedure and teacher development programmes.

Science Teaching and Learning

Teaching and learning are complex processes and context dependent (*Teaching of Science position paper*, *NCF 2005*). Any science curriculum becomes meaningful and fruitful only when students are able to apply at least some of the science concepts in their daily life, otherwise their knowledge of science remains bookish, sterile and irrelevant in their lives. The transaction methods and strategies employed, contextualisation and innovative learning aids used for inculcating scientific temper, attitude and learning science concepts are examined in this section.

Scientific Temper

An important area of research on science teaching is inculcation of scientific temper and scientific attitude. Scientific temper is an attitude to different questions that arise in normal life of a human being (Panchapakesan, 2006). Lakshminarayan and Sreekala (2001) examined the correlation between science ability and science understanding in students. They found that science application ability was related to science process skill. Persons having advanced process skills showed higher ability to apply science in day to day life. The study was conducted in Koyilandy taluk of Calicut district in Kerala in which a total of 180 students of Class VII were randomly selected from six schools, using cluster random sampling method. Another study (Pant and Maitra, 2002) observed that talented students in science possessed positive attitude towards science. The study included 205 students of Classes IX and XI of two reputed public school in Delhi. Kartikeyan and Mohideen (2005) also reported that a positive correlation exist between the availability and utilisation of physics laboratory facilities and students attitude towards physics practical which leads to attainment of scientific attitude. Ahamad, Raheem and Hasan (2003) in a study of 'Attitude of Secondary Students towards Science in relation to sex, socio-economic status and intelligence' did not find any difference in attitude towards science between male and female students. The students belonging to high socio-economic status showed more positive attitude towards science than their middle and low counterparts, and the students possessing high and middle levels of intelligence showed significantly greater attitude towards science. Moreover, the students of middle level intelligence showed relatively better attitude towards science than their low counerparts. Ahmad (2008) examined the role of a teacher in inculcating scientific temper amongst students. It was found that the responsibility of developing scientific temper among the students lies on teachers who can provide a variety of situations to instil in students the characteristic features of scientific attitude and at the same time present themselves as an example to the students. Pachaury (2006), in a study conducted on intellectual and procedural honesty on student-teachers in the practicals conducted by them, found a very low index of intellectual and procedural honesty. The study was conducted on 30 graduate and post graduate science student teachers studying in a B.Ed. college in Bhopal.

Sengupta and Chakraborty (2005) reported that a significant number of students at the upper primary and secondary grades, and even the trainees in different teacher education institutions, who aspire to be science teachers in near future, fail to show the evidence of scientific reasoning. The study was conducted on a sample of 794 students from Classes VII to X from different schools and 150 pre-service trainee science teachers from different teacher education institutes in Kolkata suburbs. Lakshminarayan and Lalitha (2002) examined the correlation between the attitude of students toward laboratory work and their performance in theory and practical. It was found that the attitude of students towards laboratory work does not influence their performance in theory and practical. It also concluded that the achievement of students in theory is independent of their attitudes towards laboratory work. Male and female students do not differ in their attitude towards laboratory work and there was no difference in their achievement in both theory and practical. The sample consisted of 120 students from CBSE, State government and private management schools of 10+2 students. Kumar (2013), in a review of empirical studies, reported a positive relationship between science classroom variables and student attitude towards science, however the results were not conclusive.

The results of the studies, discussed above, shows that the ability to apply scientific applications is closely related to the science process skill. However, no conclusive relationship can be drawn between scientific temper and scientific attitude and more studies are required in this area.

Teaching Strategies

A number of teaching strategies for transacting curriculum have been studied. These include concept mapping method, inquiry method, problem solving approach, open-ended approach, project based method, etc. The studies clearly show the positive effects of alternative teaching methods in learning of science.

Dwivedi (2014) examined the effectiveness of inquiry training model in teaching science at secondary level. Four chapters of physics of Class IX were taught to 50 students through inquiry training model method and 50 students through conventional method. It was found that gain and retention of students receiving instruction through inquiry training model method was relatively higher than that students receiving instruction through conventional method. Kharatmal (2009) reported a significant increase in student understanding in the depiction of concepts and propositions using the concept mapping method as compared to the descriptive method. Positive impact of concept mapping strategy for improving the achievement of students of Class XII in organic chemistry has been reported (Sharma (2014). Sharma's study was conducted on 80 science students of Central Hindu Boys School, Varanasi, where pre-test, post-test non equivalent group design was used. Shailja (2009) also found concept mapping as an effective strategy to enhance student learning.

Basu and Thangasamy (2005) examined the effectiveness of small-group discussion with framing questions on comprehension of concepts in Physics at higher secondary level. The study was conducted on 60 students of Class XI. The results showed that the experimental groups taught with small group discussion with framing questions method showed improvement in comprehension of concepts in physics compared to their counterparts taught by small group discussion and traditional teaching methods. Kalia (2005) reported effectiveness of mastery learning strategy over inquiry model on the achievement of students in science at Class VII level. In another study (Smitha and Rao, 2009) it was found that teaching through discovery learning facilitated inculcation of critical thinking among secondary school students as compared to traditional method. Sridevi's (2013) study showed that constructivist teaching is more effective than conventional teaching in terms of perception of nature of science among Class VIII students. Kishore and Tamhane (2013) reported children learned the effects of force better when hands-on activities related to daily life situations were given in comparison to the activities given in textbooks. Sharma (2002) found that students developed an appreciable mastery in practical skills of following instructions for doing practical work, reporting and drawing conclusions when proper instructions were given to students. The study was conducted on a sample of 33 students (20 boys and 13 girls) of Class X.

The effect of some innovative methods on science teaching has been examined. These included mobile science laboratory in schools (Avatar, 2000), constructivist method (Bala and Tandon, 2009), and non-directive teaching (Chanda and Mitra, 2000) for school students. Jain (2002) reported strategies for problem solving and creative thinking in science education. Jogi (2011) found that involving underprivileged students in participatory video activity fostered learning in science. Mody (2011) reported constructivist method for teaching physics concepts using problems where multiple intelligence can be developed among students and a dynamic assessment can be done while they learn. Mody and Pradhan (2011, 2014) have suggested a series of innovative ways on problem based learning in basic physics. Aggarwal (2003) suggested that open ended learning in chemistry was a learner friendly mode. Gupta (2010) reported that science is learnt best when it goes beyond the four walls of the classroom and addresses the concerns and problems of the larger community because then the science becomes alive and vibrant. Teacher should act as a teaching aid herself as well as she has to provide good environment and freedom of thought so that the children can pose novel ideas for learning science without using the boredom of books. Mehra and Mondal (2005) reported better learning outcomes in terms of achievement in science using peer tutoring than traditional instructional teaching.

Mohanty and Panda (2009) analysed learners' engagement in secondary school bioscience activity on a sample of 143 students of secondary school in Odisha. They reported that 73 per cent of the sampled students developed interest to know more about bioscience. They liked to complete home task, write essays, articles, small poems, stories and preparing reports in the process of learning bioscience. They also reported that students' participation in seminar, debate, group discussion, etc., was unsatisfactory and attributed it to the lack of opportunities. Pareek, Vidyapati and Arya (2012) studied the impact of micro scale laboratory kits on students' achievement in chemistry practical and found that working with micro-scale chemistry kit for one academic year helped students to improve their chemistry practical skills but did not help in improving their cognitive skills. Gangoli and Gurumurthy (2013) examined the effectiveness of open-ended approach for conducting physics experiment. They found that guided open-ended approach is better than the traditional laboratory approach in the promotion of cognitive abilities like knowledge and understanding whereas it does not have marked difference in developing creativity.

Innovative Methods

Researchers have developed innovative methods of teaching different science concepts. Included among them are—analysis of environment pollutants such as sulphur dioxide, nitrogen oxides (Sindhu and Sharma, 2002), evaluation of Planck's constant using torch bulb and light emitting diode (Dash and Mahapatra, 2007), verification of Boyle's Law (Bapat and Rao, 2002), inexpensive atomic and molecular models (Gupta, 2000b), learning science concepts with discarded materials such as soda straw, plastic bottles and polythene bags (Kishore, 2003, 2006), integrating critical thinking skills in classroom (Shaffi and Ravichandran, 2002), mole concept (Mehrotra and Koul, 2012), measuring focal length of a lens using low power laser (Ratna, 2001), etc. Story telling as a constructivist tool in science teaching was examined by Tandon (2011) and found improvement in the performance of learners. Maitra (2009) applied the projective motion of cricket ball to explain science concept in the game of cricket. A number of innovative problem solving activities for senior secondary biology students were examined (Shaffi, 2000). Lambhate and Choudhari (2013) developed an innovative way of teaching science using Bullock-cart. Parkash (2000) reported innovative way of assessing toxicity of nitrates and nitrites. Praveen (2012) reported effectiveness of tree-chart for teaching botany at higher secondary level. Seetharamappa (2012) reported innovative way of learning periodic table through games. Gupta (2000a) reported simple procedure for demonstration of the pressure effect in NO_2–NO_2 equilibrium state. Likewise, Shukla, (2000) reported an innovative method of linking electrode potential for predicting the products of the reaction in chemistry. Mali (2001) reported the detailed analysis of the buoyant force and its connection to fluid pressure. Sengupta (2001) discussed innovative methods of concept learning in science and reported that the meaning of a scientific concept is scientifically valid only if what scientists intended by it becomes actual, i.e., problems are solved and intentions are fulfilled as enquiry continues.

Teaching-learning is a complex process, however some effective teaching strategies are reported in this review such as concept mapping approach, open-ended approach, problem solving approach, conducting hands on activities related to daily life, etc. A number of innovative methods for teaching specific concepts are also reported; however, this requires further testing before implementing at the mass level. These innovative strategies or methods are pointers which can be adopted for bringing improvement in teaching-learning process.

Creativity

Creativity research in the early years focussed on conceptualisation, identification and assessment of creative talents. However, as Grewal (2000) reported, the research conducted during the past four decades has shown that creativity can be fostered and has advocated for adopting curricular approaches for training of creativity. Gupta (2000) opined that the concept of creativity is a multifaceted phenomenon and offered some suggestions on how creativity can be nurtured through chemistry curriculum.

Visual representation or visualisation is main focus in a number of studies for inculcating innovation and creativity. The articles, by Ramadas (2013) on 'Visual Representation of Water Cycle in Science Textbooks', Kala and Ramadas (2009) on 'Visual and Spatial Modes in Science Learning' and Mathai and Ramadas (2009) on 'Visuals and Visualisation of Human Body Systems', all reported the role of visualisation in creativity, in building mental models and in the communication of scientific ideas. Prior knowledge strongly influences the visualisation and comprehension of texts and diagrams including the ability to move flexibly between texts and diagrams. These visuals and texts also need to be appropriately integrated within the textbook. Aggarwal (2000) found that creativity is a developmental process which flourishes best in a free and relaxed atmosphere in a truly democratic set up. It also suggested that divergent thinking, which results in creativity, can be promoted through open education. Dogra (2010) observed that a creative teacher can identify the talent in a child or they can make the boring topic more interesting by performing some simple classroom or school activities which encourages thinking, understanding, exploration, problem solving, collaboration, problem solving, collaboration, analysis and prediction for learning of different subjects. The studies thus show that creativity can be nurtured in children by providing stimulating environment to think and explore, and by encouraging divergent thinking and visualisation. This, of course, has implications for developing teaching-learning materials and adopting suitable teaching strategies.

Gender Concerns in Science

Gender issues have emerged as one of the most important topic in the perspective of science education in the Indian context. Throughout the history, women had limited access to education and technology. The participation of women in science and technology even today is relatively on the lower side. Any technology is the product of social relations and forces and choices are shaped by the social arrangements. As discussed by Sugra Chunawala in the chapter, 'Education and Technology Education within the Gender Perspective' (2004) in the book '*Books for Change*', the education system plays an important role in the formation of gender identity. Today, science and technology are viewed as masculine disciplines. However, the major concern is less interest shown by women and girls toward science as compared to men. It is established that cognitive ability is not the reason for difference between the interest of boys and girls in science. Kishore (2004) observed that popular media projection of scientists as eccentric seems to be keeping girls away from physics courses. He further mentioned that if lesser number of girls are attracted to science courses, then it is the matter of attitude and the queer image of science teaching as being remote, difficult and masculine.

Raveendran and Chunawala (2015), employing a feminist critique approach, examined how values get communicated in biology curriculum. They reported that while the reproductive approaches focus more on the pedagogy of science and attempt to incorporate learning styles and examples that are closer to the lived experiences of girls and ethnic minorities, they essentially reproduce the knowledge structure without questioning it. Resistant approaches, on the other hand, go a step further to question the fact-value dichotomy that is rigidly maintained in the science curriculum and seeks to relocate science in a socio-political context. The authors (Raveendran and Chunawala, 2015) suggest that textbook writers and teachers need to reflect and make explicit the value-frameworks that underpin the 'facts' communicated to the students.

The results of the studies examining gender differences in science are not conclusive. For example, in a longitudinal study, Gafoor (2013) found that interest in physics has declined more among girls than boys. Even in general, the decline of interest of girls is more in physics than interest in science, while decline of interest of boys is less in physics than interest in science. Vidyapati and Prakasa Rao (2003) reported a significant gender difference in favour of girls in science achievement. However, no significant gender difference in scientific attitude and scientific creative abilities was observed. In another study, Sharma (2002) examined science practical skills of students at secondary level. The practical task was drawn from secondary curriculum and was administered to 33 students (20 boys and 13 girls) of Class X to assess their performance in the skills of following instruction, reporting and drawing conclusion. The results reported an appreciable difference between the performance of boys and girls. Agarwal and Gupta (2010) on a study conducted to assess the problem solving ability in physics among intermediate level students in relation to their sex, locality and types of school. The findings indicate that sex and type of school both influenced physics problem-solving ability of the students. Students of privately managed schools and girl students have better physics problem solving ability than their respective counterparts.

More discerning efforts are, obviously, needed to remove gender bias from textbooks and classroom practices. Gender sensitisation of teachers both at the pre-service stage and during in-service training is necessary to promote gender-fair science education. The curriculum should also strive to make the contribution of women to the field of science and technology 'visible'. Teachers should be sensitised to promote equitable classroom practices to ensure 'science experiences' of comparable quality to girls.

Achievement in Science

Over the years, a lot of emphasis is given to monitor and increase the achievement of students. However, the achievements of students continue to be a major area of concerns for government, researchers and educationist. The reports of the National Achievement Survey (NAS-2017) for elementary students and the National Achievement Survey (NAS-2018, Cycle 2) for Class X students present a grim reality regarding the achievement of students in the country. As per the reports, the national average score in science for Class VIII students is 44 per cent and for Class X students is 34 per cent only. Assessment and evaluation form an inseparable part of the teaching-learning process. However, the examination system in place today in the country continues to dominate the teaching-learning process. This problem is also compounded by the faulty evaluation practices followed, nature of the questions asked or the predictable and stereotype of questions asked in the examination. Ediger (2002) reported teacher developed tests can be more valid and reliable than standardised test and further argued that there is probably no better way to write valid test items than the classroom teacher doing the writing who knows and understands what has been taught in the classroom.

It has been observed that the achievement of students in life science subject differ significantly due to teaching by high and low competent teachers and also due to high and low teaching effectiveness of teachers (Banerjee, Das, and Mohanty, 2014). Further, a positive relationship between the teacher competence and teaching effectiveness were reported. The study was conducted amongst 564 students and 35 teachers in 21 schools of Birbhum and Burdwan districts of West Bengal. No significant difference was found due to CBSE and UP Board in the development of higher abilities of science students (Rizvi, 2014). A comparative study was made between the science students of Class XI from the CBSE board (who faced the CEE pattern in Class X) and the science student of the same class from UP board (who did not face the CCE pattern in Class X) in 2010–2011 in Bulandshahr district of UP. Chauhan (2001) reported methods for identifying under achievers in science and strategies for helping the under achievers to learn science. Ediger, M (2013b) report Instructional Management System (IMS) as an innovative way to appraise student progress. Koul (2008) highlighted a number of evaluation issues in science. Kumar and Kumar (2011) reported a significant relationship between psychological stress and achievement of male and female students. The study was conducted amongst 631 (419 males and 212 females) senior secondary science students randomly selected from different types of institutions of Meerut district. Mohanty (2010) reported effectiveness of programmed instruction on achievement of secondary school children in life science.

Kumar and Kumar (2013) conducted a study to assess the psychological stress and its relationship with achievement of science students of Kendriya Vidyalayas and Navodaya Vidyalayas and found examination and achievement as the major factor causing stress. Agarwal (2003) identified subjectivity in marking as a major criticism in written examination and suggested a detail marking scheme to reduce subjectivity in marking. Gupta (2001) revealed variations in different sets of question papers of the same board in terms of objectives, difficulty level and content coverage leading to wide gaps in achievement level of learners for no fault of theirs. Khatoon and Sharma (2010) explored the relationship between students' personal factors (gender, religion, family background, extracurricular activities, computer and internet access) and institutional factors (school having computers and co-educational schools) with their science achievement. The study conducted on 15 year old students from a specific geographical location of western Uttar Pradesh revealed that variables such as family background, extra-curricular activities, computer and internet access, schools having computers and co-educational schools were found to be positively correlated with science achievement, but variables like gender, religion and single-sex schools have no correlation with science achievement. A study by Sharma (2008) indicated that there is a significant difference and a wide gap between the learning outcomes as expected from the curriculum and their real learning at all levels of school education.

The review revealed the low achievement of students and a grim situation regarding the assessment and evaluation system in practice. Some assessment practices reported show promise, yet no definite conclusions can be drawn. More researches in this area will definitely guide us to go in the right direction.

Environmental Concerns

Environmental concern is an important area in school education. Some studies are reported in this area. Jackson, (2001) argued that the introduction of environmental problems into existing Indian school curricula has caused incoherence as discussed in his article 'Effective Environmental Education needs 'New' Science', and stated that even the basic assumptions underlying the current science paradigm are contradicted by the solutions to environmental problems that appear to be required. Attempts are made in the textbooks themselves to remove these contradictions, but they are largely unsuccessful and only add confusion to the initial incoherence. Here, author sketches an alternative, 'New' or 'Ecological', science paradigm and suggests how it might be taught. As discussed in the article, 'Conservation of Global Biodiversity for Sustainable Agriculture' by Kulshreshtha (2000), biodiversity is the variety of the organisms existing on globe, including their genetic variability and the assemblages they form. Conservation of biodiversity is recognised as a fundamental component of sustainable development and its objective is to support sustainable development by protecting and using biological resources in such a way that do not destroy the world's variety of genes and species or vanish the important habitats and ecosystems.

Dash, Mishra and Satapathy (2010) examined the knowledge and understanding of education for sustainable development of pre-service and in-service school teachers of Odisha and reported that both pre-service and in-service teachers had moderate level of knowledge of sustainable development. However, in general, it was found that teachers were more deficient in conceptual knowledge of sustainable development (issues like indicators of economic development, carrying capacity, global climate change, biodegradation, etc.). They also reported that there was increase in their understanding of sustainable development issues with increase in teaching experience. The implications for revision of teacher preparation curriculum and organisation of community linked in-service teacher training programme to empower teachers to understand and transact sustainable development concepts have been discussed.

Experiential learning strategy yield better mean gain on environmental awareness scores as compared to the traditional method among primary school students (Mehra and Kaur, 2010) and students with internal locus of control yield better mean gain on environmental awareness score than the students with external locus of control. Yadav and Bharati (2007) in a study conducted on environmental awareness among higher secondary students of Varanasi district in U.P reported that environmental awareness had positive relationship with scientific attitude among students and science students were found more aware about environment as compare to arts students. Vellaisamy (2010) reported that no significant positive relationship exists between achievement in environmental education and environmental awareness ability in a study conducted among Class IX students of four different schools in Vedaranyam block. It was also found that students were not having enough awareness and skills for identifying and solving environmental problem.

Nayak (2011) studied the level of awareness, knowledge and attitude of student towards climate change in B.Ed colleges of Mumbai and Navi-Mumbai. It was revealed that though student teachers of different stream, i.e., Science, Arts and Commerce were aware of the problem of climate change but they lacked sufficient knowledge of climate change with regards to its causes and consequences. Barathi, Paul and Devi (2004), in a study on environmental awareness among 296 higher secondary students in Tiruchirapalli district, found that though students have adequate environmental awareness, science students have more environmental awareness than arts and vocational students.

The Way Forward

A number of researches have been conducted mainly related to teaching of science, science curriculum, content selection in science and science teaching-learning materials. However, there are also a number of less explored areas that need attention such as epistemology of science, history and philosophy of science, and ethical and cultural issues concerned with science. Vaidya and Chunawala, in the fifth and sixth surveys, respectively, have also emphasised on studying history and philosophy of science and conducting policy studies in science education. The understanding of history and philosophy of science, epistemology of science, and ethical and cultural issues generated by science will give us an insight in designing science curriculum, teaching-learning materials and the intended pedagogical practices to be followed in teaching science. Thus, it is important that science curriculum, teaching-learning materials including textbooks are developed keeping these perspectives in mind for improving science education. Science is a systematic and organised body of knowledge and, to teach science in its true spirit, perhaps more studies are needed in the area of scientific attitude, cognition, critical thinking, creativity and misconceptions.

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