Influence of Learning Theories on Science Education*

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Educational psychologists have developed theories of learning based on three main paradigms – behaviourism, cognitivism and constructivism. Behaviourists believe that the behaviour of learners is a response to their past, and behavioural modification is the main purpose of education. According to cognitivists, the behaviour of learners is the result of his/her cognition, and the main aim of education is to change the cognitive schemas. Constructivists, on the other hand, believe that learners construct their own knowledge, and the objective of education is to provide opportunities to gain knowledge. The understanding of how children acquire knowledge has influenced teaching-learning processes in the classroom significantly. The role of teachers has changed from the person imparting information to a person facilitating the construction of knowledge. Teaching science has also been influenced by the changing psychological ideas about teaching and learning. The information age that dawned in the 20th century necessitated the acquisition of information through informal modes like listening to the radio, watching television or surfing the world wide web. Developments in digital technology have, thus, changed the way students make meaning of given information. All these changes have forced the educationists to design appropriate methods of teaching and learning. A journey into the changes that learning theories have witnessed influencing the teaching of school science is outlined in this article.

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Introduction

Science, as a discipline of formal study, got its place in school curriculum towards the last quarter of the 19th century. The founding fathers of science education attempted to teach it along with other subjects in schools in the same style. As science developed, and more science content was included in the curriculum, the science educators took cognizance of the developments in psychology. Twentieth-century educational psychologists came out with theories of learning that explained the way children acquired skills and knowledge. These theories have influenced the teaching of science significantly. Learning theories are based on three main psychological paradigms – behaviourism, cognitivism and constructivism. It would be useful to understand the basics of these three approaches and explore the influence they had on science education.

Behaviourism

In the beginning of 20th-century, educational psychology as a discipline took shape. Psychologists in those days were busy understanding the process of learning. They came out with the theory that took into account the behaviour of different animals. There were many psychologists from different countries who contributed to this development. Four of them needs special mention: Ivan Pavlov (1849–1936), Edward Thorndike (1874–1949), J B Watson (1878–1958) and B F Skinner (1904–1990). In this article, we do not wish to go into the details of their individual contributions. Instead, we will try to understand the gist of this approach and how it has affected the teaching of science in the classrooms.

Behaviourism paradigm focuses on observable behaviours. Behaviour theorists define learning as the acquisition of new behaviour based on environmental conditions.

Behaviourism paradigm focuses on observable behaviours. Behaviour theorists define learning as the acquisition of new behaviour based on environmental conditions. They identify conditioning as a universal learning process. There are two types of

conditioning – classical conditioning and operant conditioning. Classical conditioning refers to a learning procedure in which a biologically potent stimulus is paired with a previously neutral stimulus. Operant conditioning, also called instrumental conditioning, is a method of learning that occurs through rewards and punishments for behaviour.

As per the guidelines of behaviourist thinkers, the classroom interaction focussed mainly on behaviour modification. Classroom instruction where the teacher transmits information to the learner was considered to be an effective mode of teaching. It was necessary to ensure that the child acquired all the knowledge the teacher wanted to provide. Techniques to achieve such proficiency (mastery learning) were also suggested. According to the behaviourist thinkers, science teaching could be equated to making children familiar with scientific information made available to us by scientists, without attention to the method of science used by them. Some methods that were born out of this thinking are outlined below.

Transmission of Information

In this mode of interaction, the science teacher communicated scientific information to his/her students orally. Thus, the rules and laws such as Newton's laws of motion, Mendeleev's law of periodicity, Mendel's law of heredity, etc., were read out or told in the classrooms. Students were expected to listen to the teacher carefully and remember them. The lecture mode classroom proceedings would sometimes be supported by practical demonstrations. For example, the teacher would demonstrate in the classroom that the like poles of the magnet repel while unlike poles attract each other. This mode of teaching science is still practised in many of the Indian schools.

Practice was considered a major tool to ensure knowledge fixation. Sometimes it took the shape of rote learning. Scientific laws were, thus, learned by heart and reproduced in the examinations. As the interaction time in the school was limited, students

were often tasked with practice as homework. For example, if a child was to master how to balance a chemical equation, (s)he was expected to practice it a number of times at home. Repetition of the statements without committing any mistake was often construed as learning. Higher-order skills like understanding, application, interpretation, etc., were hardly given any importance in the teaching of science.

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Remedial Instruction

Remedial instruction applies to students who fail to fulfil the expectations of a teacher. As the name suggests, the focus here is on diagnosis and remediation. An attempt is made to diagnose the gap in understanding when a child has not reached the level of mastery learning expected. This thinking has resulted in the development of diagnostic testing. These tests have been prepared by dividing a major concept into small sequential subconcepts and framing questions to see if the child understands each of them. For example, the main concept of evolution would be subdivided into small concepts and questions framed on each of them. Analysis of the answers given by a child would enable the teacher to understand the nature of help that (s)he needs.

Remedial education cannot be limited to conceptual learning. It demands the development of learning skills. For many students, the lack of learning prerequisites like motivation to learn, reading comprehension, poor mathematical skills, etc., are the main learning hurdles. They need to be developed so that students can benefit from classroom proceedings. A project entitled Talent Search and Nurture among the Underprivileged was undertaken at Homi Bhabha Centre for Science Education (TIFR) to understand learning hurdles faced by students from socially deprived homes and to design appropriate remedial inputs to overcome them. The work carried out for about a decade (1980–90) showed that remedial instruction offered taking into account the learning difficulties faced by the students can not only compensate for poor initial preparation but also for social deprivation [1].

CBL Packages

A large number of coaching classes mushroomed in India to prepare students for examinations. With the development of technology, new gadgets were brought into use for practice and assessment in schools. Computer-based learning (CBL) packages were developed to facilitate repetition and practice of the content discussed in the classroom. Software programmes that enabled self-assessment were developed. A student could take the computer test and find out where (s)he stands in criterion-referenced testing. Some programmes even gave feedback to the students to know the correct answer to a question.

In a short span of time CBL packages were prepared to teach a variety of concepts in physics, chemistry as well as in biology. Study material on CDs was also made available on a large scale to the teaching community. With the availability of internet facility, the use of such packages increased substantially. Although the CBL packages proliferated, their utility as a teaching aid in science remained doubtful. In fact, some thinkers claimed that these packages debilitated science learning instead of facilitating.

Cognitivism

Sometime close to 1960, psychologists realised the limitations of the behaviourist approach and started focussing on the growth of the brain. Piaget, a leading cognitive psychologist from Switzerland played a crucial role in this aspect. He emphasised on two main functions – organisation and adaptation – in learning. Organisation refers to the fact that all cognitive structures are interrelated, and that any new knowledge must be fitted into the existing system. Adaptation refers to the tendency of the organism to fit with its environment in ways that promote survival. Based on his work with children, he came out with the four-stage model of development: 1. sensory-motor (0–2 years), 2. pre-operational (2–7 years), 3. concrete operational (7–11 years) and 4. formal operational (11+ and more). He advocated that the teacher should be conscious of the developmental level of the child, and the con-

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tent to be taught should be appropriate to the stage at which the child stands. The teacher, in the opinion of Piaget, should first analyse the task to determine the level of reasoning required for its successful solution. He went further to suggest that the teachers should motivate learners by emphasizing problems and trying to jolt them out of their ordinary way of looking. Whenever possible, Piaget said emphatically, to have learners perform some relevant physical action on an object. This thinking had a profound effect on classroom pedagogy.

Cognitive theories emphasize making knowledge meaningful and helping learners organize new information in his/her cognitive schema.

As stated above, cognitive theories emphasize making knowledge meaningful and helping learners organize new information in his/her cognitive schema. To make instruction effective, it must be based on the student's existing mental structures. It should help learners to connect new information with existing knowledge in a meaningful way. Analogies and metaphors are examples of this type of cognitive strategy. Other cognitive strategies may include the use of concept mapping and advance organisers. The spread of cognitivism among science educators had a profound effect on the teaching of science in schools. New methods were developed and tried on a small scale. Science education journals received a large number of articles based on these methods in the 1970s and 80s.

Activity-based Teaching

Science education, influenced by behaviouristic thinking, was limited to theoretical discussions providing declarative knowledge. Soon, however, science educators realized the importance of procedural knowledge. As a result, laboratories were built in schools where students were given an opportunity to perform simple activities [2]. Here, the focus was on developing laboratory skills among the students so that they can design and perform experiments on their own.

A project initiated by Nuffield Foundation in England can be cited as an example of activity-based teaching of science. In this

project, the academicians from different disciplines worked on developing a laboratory programme for effective teaching of science. A laboratory manual was made available to the teachers in print form. The impact of this project has been long-lasting on the teaching of science [3]. Even today, some of the experiments developed by experts working on the Nuffield Science Teaching Project are used by practising teachers. A group of scientists in India initiated a Hoshangabad Science Teaching Project (HSTP) based on the idea of learning through activities. Textbooks were prepared and made available to a large number of schools in central India. Training courses were conducted to acquaint the teachers with the new philosophy. Assessment of this project showed a positive impact on the understanding of the students [4].

Inquiry Method

Advocated by Suchmann, the inquiry method focuses on creating puzzling situations for students to start enquiring. By encouraging students to inquire into day-to-day problems, they are entrusted with greater opportunity and responsibility of self-learning. This teaching method suggests that the teachers should not provide ready-made answers but should encourage students to seek answers themselves. Teachers should interact closely and spend time with students analysing their inquiry strategies, and help them find answers to their questions. This mode of teaching is in line with the development of science as immense knowledge can be gained by asking questions about the occurrence of natural phenomena.

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Children, by nature, are curious. They have a variety of questions on their minds about many things around them. Unfortunately, our education system hardly provides an opportunity to satisfy this curiosity. Given an opportunity, students question many aspects relevant to daily life. Providing direct answers to their questions would satisfy their curiosity temporarily. Instead, showing them the method to seek answers equip them to gain new knowledge [5].

Expository Teaching

Ausubel, the advocator of this method, held the view that learning is meaningful only if a learner can relate it to the ideas that (s)he already understands. To facilitate such a linkage, he suggested the organization of lessons according to the process of progressive differentiation, moving from general to the specific. He coined the phrase 'advance organisers' which essentially mean either to activate students' reception system or to equip them with the necessary receptors they do not have.

Relating the concepts and principles learned early in the course to the ideas presented later in the course is very important in this method of teaching. For example, recalling the fact that liquid water takes away heat during evaporation is essential in explaining why water is used in extinguishing fire. Lesson planning by the teacher plays an important role in this method of teaching. Teachers are expected to plan their inputs and activities in such a way that students acquire knowledge in a step-by-step manner, relating new information to what they already know. This procedure leads to a better conceptual understanding of science.

Constructivism

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Two types of constructivism emerged in the late 1970s. Lev Vygotsky introduced social constructivism, in which social interaction with others was deemed helpful to the learner in giving meaning to information. Vygotsky noted that learners can develop a certain level of meaning on their own, but it can grow even greater after interacting with classmates and instructors. Thus, Vygotsyian approach takes the socio-cultural context into account and advocate close teacher-pupil interaction as a crucial component of learning. In 1985, Jean Piaget introduced cognitive construc-

tivism, in which knowledge is considered to be constructed by either assimilation or accommodation. In assimilation, incoming information is associated with the existing schema. When incoming information does not match the existing schema, then it must be changed to accommodate this conflict.

Constructivism is best utilized when learners take control of the learning situation, such as in problem-based learning. As learners engage themselves in an activity like this, they develop an understanding of the importance of the problem, comprehend the relevance of the topic, and construct knowledge through their experiences. It is more important to focus on the whole rather than the individual parts in constructivist learning. Constructivism is sometimes misconstrued as a theory that compels students to reinvent the wheel. It, however, implores students to attempt to learn how it functions and apply this to real-world learning.

The formulation of learning theories based on constructivist thinking had a notable influence on the teaching of science [6]. A large number of innovative projects were undertaken all over the world to develop methods and materials for effective teaching of science based on this thinking. The constructivist approach attempts to provide opportunities for interaction to the learners so that they can derive meaning out of it. The role of a teacher is to create situations and provide facilities to help their students in their endeavour of gaining knowledge. In this context, three methods can be mentioned prominently: project-based learning, discovery approach and conceptual change method.

Project-based Learning

Project-based learning allows students to learn by doing and applying ideas. Students engage in real-world activities that are similar to the activities that adult professionals engage in. A project-based classroom allows students to investigate questions, propose hypotheses and explanations, discuss their ideas, challenge the ideas of others, and try out new ideas. It is drastically different

from direct teaching methods.

In this method of teaching, the entire science syllabus is divided into projects/activities to be carried out by the students. The teacher provides adequate resources to the students to complete their work. A project is usually assigned to a small group of students so that they can collaborate with each other in completing the task and acquire new knowledge. Adoption of this method, however, adds to the workload of the teacher. A lot of preparatory work is required on the part of the teacher to motivate the students to undertake the task. The teacher needs to identify suitable projects that can sustain the interest of students and facilitate their understanding [7]. Hence, this mode of teaching is not yet very popular among teaching communities. Instead of covering the whole syllabus through the project method, teachers generally tend to suggest some projects on which the students can work in small groups.

Discovery Method

Bruner, a well-known American psychologist, advocated the discovery approach for teaching science. As a first step, he suggested teaching the basic structure of the discipline along with the relationship of the most important concepts and principles. Once this scaffolding is ready, discovery learning techniques can be used to motivate students, help them retain information and teach them how to learn. In this style of lesson planning, the discussion should begin with a problem. As the students attempt to deal with the problem, they not only learn the basics concepts involved but also acquire skills to gain knowledge.

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Discovery method has become quite popular in science education globally. A variety of projects have been undertaken to try out this pedagogy on small as well as large scales. It was suggested that this method leads to insightful learning as advocated by Wolfgang Kohler. In India, the Hoshangabad Science Teaching Project (HSTP) that was initiated as activity-based teaching attempted to implement the 'discovery approach'. It provided opportunities

to learners to conduct activities, collect data and discuss its relevance to everyday life. HSTP was a widely appreciated project and led to large scale expansion in the state [8]. This philosophy advocated that the child should play the role of scientists in the school laboratory, and should collect datum, analyse it and arrive at a conclusion using scientific methods. There are, of course, limitations to this method. One is not sure that the students would discover the same principles as was done by great scientists like Newton, Galileo, Faraday, Mendeleev or Darwin. Hence, there is a need for constant supervision and guidance by the teacher.

Conceptual Change

Children go on constructing knowledge based on the experiences they gain in their everyday lives. The conclusions they draw or the rules that they perceive about Nature may many times not match with the accepted scientific facts. Such ideas are considered as misconceptions or alternative conceptions [9]. Research shows that almost all primary school children believe in the Earth-centric universe. It is the duty of the teacher to ensure that such misconceptions are clarified through appropriate explanations and activities. Similarly, a large number of students think that it is the heart that produces blood. It takes time to convince them that the heart is only a pump, and the blood is produced in bone marrows.

One of the major influences of constructivistic thinking on science education has been the study of alternative concepts. Initiated by Rosalind Driver, a large number of researchers have taken up studies in this area and have come out with alternative conceptions possessed by students growing in different cultures. An important outcome of their work has been the identification of misconceptions among students and the development of methods and material to bring about conceptual changes [10]. The teacher following this method has to first identify preconceived ideas of students and see whether they match with accepted notions. If not, provide explanations and inputs to bring about appropriate changes in their understanding. The conceptual change model

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was tested in some selected areas. The special issue of *Science and Education* [11] was brought out in July 2014 by compiling the experiences of different science educators working in this area.

Conclusions and Implications

The 20th century has witnessed a paradigm shift in school education. This shift is due to the influence of changing ideas in educational psychology.

The 20th century has witnessed a paradigm shift in school education [12]. This shift is due to the influence of changing ideas in educational psychology. As the learning theory moved from behaviourism to constructivism, classroom interaction also witnessed changes [13]. It must be noted that new learning theory has not made earlier theories obsolete. The learning theory to be used for classroom interaction depends on the topic to be taught and the objective to be achieved. If a certain skill is to be developed among the learners, then a behaviouristic approach would prove useful. Instead, if the focus is on the cognitive development of schema, then a cognitivistic approach should be adopted. If the purpose is to make the child an independent learner then one needs to adopt a constructivistic approach. It is the judicious combination of these theories that will lead to the overall development of young children.

Science education as a field of research got established in recent years [13]. It is an interdisciplinary subject on the borderline of science, psychology and sociology. Science educators looked at the teaching-learning process as a branch of science [14]. They also took cognizance of developments in other areas like sociology, economics, technology, etc., along with science. Taking into account these developments, they have designed effective teaching methods and have developed appropriate teaching-learning materials. They need to be passed on to practising teachers who have the responsibility for preparing students to face the challenges of the 21st century. As Hodson [16] says, "this is a time for action and efforts must be made to change classroom practices by educating the teachers both through pre-service as well as through in-service training courses".

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