Science & Science Teaching

Dr. K. M. Rajan, Associate Professor
frmanirajan@yahoo.com

The quality of science education is a pervasive concern in educational improvement efforts. Until the 1950s, science teaching was essentially content-oriented and the prevalent instructional delivery system was lectures. But, the launching of Sputnik in October 1957 acted as a catalyst for a rethinking among science educators all over the world. The science competency of Russia was envied by the science educators, especially in the United States of America. The event provided a strong impetus to revitalise science education in the United States (Welch, 1979). India in her post-independent decade was re-examining the Wardha Scheme (1937) and was trying to understand the then existed secondary and university education.

In an effort to improve science education, two general strategies have been advocated. First strategy is to change the content of contemporary science courses (see, Crane, 1976; Duschl, 1990). Second strategy advocates change in the instructional practices based on current views of nature of science and learning processes. This chapter examines the second strategy based on different views about science, followed by the impact of research on learning processes.

The word science comes from the Latin noun '*scientia*', meaning knowledge (Barnhart, 1988). The view of science implied in this meaning is that science is a body of knowledge. But, few would content that science as a body of knowledge describes adequately the nature of science. The facts and laws of science paint only a partial picture of the whole enterprise. That is, a fact being the truth at hand at a given point in time cannot capture what science is, but can only help in understanding what science is. A complete depiction of science should include what we know of the field and what the body of knowledge can provide in the process of understanding (Krug, 1960). For example, the facts about electronic configuration of atoms help us to understand the tendency of atoms to undergo reaction. Thus, the worth of current knowledge (body of knowledge) is in the leverage that it affords to unearth new knowledge.

Theories of science that we accept at any given time are chosen because they function significantly in the process of knowing rather than as factual representations of some reality (Ross, 1971). For example, the general gas law, PV = n RT, molecules are conceived to be perfectly elastic point-particles devoid of any inter-molecular force of attraction. However, there is no perfect gas (those that strictly obey gas law) and the fundamental assumption of perfectly elastic point-particle is false. Yet, the "false assumption" provides a theoretical foundation for the gas law. Thus, science is an on-going process of refining knowledge and "the scientific knowledge is tentative - - affected by the process used in its construction..." (Welch, Klopfer, Aikenhead, & Robinson, 1981).

A popular conception of science is that it is either a product or a process. The dichotomization of science into product (a body of knowledge) and process (a process of knowing) is a distortion of the nature of science (Robinson, 1968) for the process of knowing is inseparable from what is known. The process of knowing and the knowledge used in the process of knowing are equally important. Sir Isaac Newton once testified: “If I have seen farther than Descartes, it is by standing on the shoulders of giants” (Wilson, 1937). The value of what we know is important in our efforts to understand things. Therefore, science should be considered both a product and a process for the process would not be meaningful without product.

Instructional Practices in Science Education

Instructional practices identified and characterized in the science education literature can be broadly classified into two - - product approach and process approach. These two categorizations stem from two different views about science that are elaborated above. That is, science as a body of knowledge and science as a process of knowing. Instructional practices based on these views have different assumptions about the learner, conceptualize learning differently and propose different learning outcomes. A brief discussion of these differences will help to provide a foundation for understanding the instructional approaches typically found in science education.

Product Approach

Product-oriented approach (also known as traditional) to science teaching makes the assumption that mind is a ‘tabula rasa’ or ‘blank slate’ and that the student is a passive consumer of information, an empty vessel waiting to be filled with scientific facts (Popper, 1972; Osborne & Wittrock, 1983; Driver & Bell, 1986; Cleminson, 1990). Consequently, much of traditional science teaching consists of textbook instruction where “assign, study, discuss, and test” (Welch, Klopfer, Aikenhead, & Robinson, 1981) and “show and tell” (Stake & Easley, 1978, Vol. 2 p. 13:62) techniques prevail. It has been well documented that students taught with this approach to science education tend to view scientific knowledge as finite, isolated bits of information (Dewey, 1910; Dewey, 1945; Pode, 1966; SAPA, 1966; McAnarney, 1972; Tasker, 1981; Driver & Bell, 1986; White, 1988; Cleminson, 1990; Hewitt, 1990; Stinner, 1992), where many students fail to develop scientific reasoning skills.

Students view scientific knowledge as finite mainly for two reasons: (1) science is presented as a set of “right answers” and (2) learning of science emphasizes memorization of established facts and applying mathematical formulae to problems by matching the variables and performing algebraic transformations. The qualitative reasoning that is necessary for causal analysis is absent in this product approach. Moreover, by presenting science as a set of “right answers” students are turned off in their attempts to make sense of new experiences (Driver & Bell, 1986). And teachers, with a very few exceptions, view the purpose of science teaching as a means to stuff students’ minds with facts in order to prepare them for the next level of schooling (Welch, Klopfer, Aikenhead, & Robinson, 1981) and students take it for granted that the knowledge is finite.

Students view scientific knowledge as independent and isolated bits of information for two reasons. First, students perceive lessons as isolated events whereas the teacher held the view that the lessons are parts of related series of experience (Tasker, 1981). Second, the formal ideas of science often conflict with students’ prior knowledge (Cleminson, 1990). Even though students store in their memory the scientist viewpoint taught by the teacher, which is not the way they really think about things. In the research literature, students' view-points or pre-conceptions are also known under different names, viz., phenomenological primitives, misconceptions, alternative frameworks, and children's science. For example, in the case of a book resting on a table, students believe that the table does not exert a force on the book (Brown & Clement, 1989). Thus, students have a preconceived notion about the fact that will be taught in the class. Consequently, students have two concepts about the same idea; one for use in science lessons and the other they find plausible for everyday living. These two viewpoints that are contradictory cause students to fail in making connections that are expected in the learning of science.

Process Approach

An alternative to the product approach, the process approach, focuses on the learning of inquiry skills more than specific content (Gagne, 1963; Livermore, 1964; SAPA, 1966; Gagne, 1967; Harlen, 1978). Research on the constructive nature of students' learning processes (Osborne & Wittrock, 1983), mental models of phenomena that evolve through students' interaction with environment (Gentner & Gentner, 1983; Norman, 1983), and intuitions based on observations of physical events that stand without significant explanation and justification (Wheeler & Kass, 1978; Novick & Nussbaum, 1981; Osborne & Cosgrove, 1983; diSessa, 1983) suggest that students actively generate meaning from experience which influence the ways in which they respond to and understand disciplinary knowledge.

Several projects were designed in science, taking into account the objectives of process approach and anticipating integration of knowledge. Projects such as Nuffield Junior Science in Britain (Harlen, 1978) and new courses in chemistry such as Chemical Education Material Study (CHEM-study), Chemical Bond Approach (CBA), and Science-A Process Approach (SAPA) of the American Association for the Advancement of Science (AAAS) in the United States are a few along this direction (Pode, 1966; SAPA, 1966). These projects emphasised processes of science such as observing, classifying, inferring and predicting rather than the content of science.

Beyond Product and Process Approaches

We have seen in the preceding pages that teaching of science revolved around the concept of science as a body of knowledge and as a process of knowing. These two concepts focus on the nature of science and not on the learning processes. What will be developed in the following pages will provide an insight into learning process with details of learner characteristics. Theoretical propositions and empirical findings that illuminate learning of science are: (1) students should actively engage in the learning task and (2) students should have chances to explore in their own fashion so as to integrate knowledge. Of the two aspects of learning of science, the active engagement of students in the personal construction of new knowledge is by far the most critical in the successful study of the subject. Each of the two aspects that go beyond the definition of science is examined below.

Students should actively engage in learning

Students' active engagement in learning of science is often mistaken to be laboratory work. It is true that laboratory work has served as an instructional strategy for teaching science either alone or in combination with other methods. Laboratory work usually follows two distinct patterns - - one in which students rediscover scientific laws and principles and the other in which students perform verification experiments through which a "known" answer is sought. The former pattern involving rediscovery is time consuming and unwarranted use of time and energy (Hodson, 1985) since the expected outcome pre-supposes stereo-typed engagements of students which are rarely found in practice. Apart from that, a student under directions from an able teacher may acquire laboratory skills (by physical manipulations of tools and materials) that will still be inadequate to practise those inquiry skills.

The latter pattern of verification experiments may develop habits of care and precision in making and recording observations, but care and precision are necessary but not sufficient conditions to equip students for learning science. What is desired is a self-directed learning environment that seeks to maximise further learning (Easley, 1959). Then, the relevant question is, "how to provide learning environments?" that will help students in further learning using familiar materials of daily life as tools to understand nature. To be effective, the active engagement should take into account students' familiarities together with materials within their personal world as opposed to a world that exists only for scientists (Dewey, 1945).

Hawkins (1965) described active engagement of students as 'messing about.' The messing about denotes free and unguided exploratory work that will provide the cognitive basis for thinking and reasoning. For example, Hawkins's fifth-grade class was provided with frames, strings and bobs without any direct instruction as to what they should do with the apparatus. Interestingly, most of the questions that a teacher might have planned, unfolded from their 'messing about' with the apparatus. That is, Hawkin's students varied the conditions of motion in many ways, exploring difference of length, using different sorts of bobs, bobs in cluster, etc. Autonomous activities such as those mentioned help students build a background knowledge that can later make sense in deriving abstractions (Piaget, 1973). Dewey (1945) cautioned that students are repelled by a premature diet of abstract scientific propositions that lack in meaning to them when abstracted from the familiar facts of experience. "What is needed is to hitch the horse of concrete experience with daily occupation and surroundings to a cart loaded with specialised scientific knowledge" (Dewey, 1945, p. 123).

The proposition for students' active engagement is also a psychologically sound principle, for active engagement provide those opportunities for recreating ideas themselves rather than accepting an entirely organised body of knowledge from outside (Piaget, 1973). This active engagement in itself is oriented towards methods of knowing and thinking (Harlen, 1992). When students actively engage, resulting in the construction of knowledge, they do so by relating the experience (resulting from engagement) to a previously acquired psychological frame (Bruner, 1973). That is to say those students generate meaning to their experience in relation to what they know. This is referred in the science education literature as the constructivist perspective. From the constructivist perspective, learners are responsible for their learning in that they have to direct their attention to the learning task, draw on their present knowledge to construct meaning for themselves and evaluate that meaning (Driver & Bell, 1986). Therefore, the teaching task demands allowing students to engage in activities that help them organise their own experiences successfully and in a way that makes sense for them.

Students should have chances to explore in their own fashion

Learning can no longer be considered as a single route from point A (E_B - Entering Behaviour) to point B (T_B - Terminal Behaviour). This is because of the fact that point A or the entering behaviour of the learner is qualitatively different to the extent that individuals are different. Most often than not, teachers' preconceived route or method to lead students from point A to point B or the terminal behaviour may not be appropriate because of students' learning styles and previous knowledge.

Several studies reveal that brain is much more than a blank slate and that it ignores some information and selectively attend to other information. Using the Interview-About-Event technique, Osborne & Cosgrove (1983) investigated children's conceptions of what is happening when water changes its state from liquid to vapour. Children's responses - - "bubbles are made of air," and "bubbles are oxygen and hydrogen" confirm that they held different views about the bubbles in boiling water. Similarly, in a cross-age study, only a small percentage of students accepted the idea that there is empty space between gas particles (Novick & Nussbaum, 1981). In a study of 12th grade chemistry students Wheeler and Kass (1978) reported that 82% of students were found to possess misconceptions about how fast a reaction proceeds and how far the reaction goes in chemical equilibrium. Therefore, it is imperative that teachers should attempt to design learning experiences that build on rather than ignores students' views.

Students should have chances to explore content areas in their own fashion because they have different concepts about the topics with which they are interacting. These concepts or intuitions demand different routes in learning and seek answers to different questions so as to integrate knowledge with their existing knowledge. New knowledge should be firmly anchored to existing knowledge (Hodson, 1985) for which students should be encouraged to grapple with incoming information to make multiple connections. Also, the ways of knowing are dependent on the style of the individual learner (Eylon & Linn, 1988).

Use of multi-media instructional techniques capitalise on the diverse possibilities of students' interactions. Students should have chances to pick and choose learning experiences because a single perspective is almost never enough to build a well-integrated understanding (diSessa, 1988). Mega-microworlds have been suggested so as to create multiple routes through a learning material. The idea of mega-microworld is that it is necessary to build clusters of microworld (interactive computer simulations) so that students can become involved in many ways over an extended period of time. Thinker Tools (TT) developed by White (1988) facilitate students' engagement with required flexibility to explore ideas in their own style. The Thinker Tools present concrete and perceptible interactive computer simulations which are easy to manipulate. For example, how forces affect motion of an object was presented by wakes and datacross for students to learn the relationship qualitatively. This mode of learning provides for students' prior knowledge and diverse possibilities and preferences in learning, incorporating elements of scientific inquiry.

In short, teaching and learning in science which revolved around the definitions and nature of science should now go beyond such considerations. The reason for this is that students have their own concepts about each and every topic that they learn prior to formal instruction. Moreover, these concepts are remarkably different in their quality to make sense of new knowledge. Thus, learning experiences need an orientation that should be explored from students' perspective rather than of a teacher. Teachers should arrange opportunities for students' active engagement with due recognition to their prior knowledge (intuitions, alternative frameworks, misconception and phenomenological primitives) which will result in the development of inquiry skills and integration of knowledge.

References

Barnhart, R. K. (Ed.). (1988). *The Barnhart dictionary of etymology*. The H. W. Wilson Company.

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science*, *18*(4), 237-261.

Bruner, J. (1973). *Beyond the information given*. New York: W. W. Norton & Co.

Cleminson, A. (1990). Establishing an epistemological base for science teaching in the light of contemporary notions of the nature of science and how children learn. *Journal of Research in Science Teaching*, *27*(5), 429-445.

Crane, L. T. (1976). *The National Science Foundation and pre-college Science education: 1950-1975.* Washington, D. C: U. S. Printing Office.

Dewey, J. (1910). Science as subject matter and method. *Science*, *1*, 121-127.

Dewey, J. (1945). Method in science teaching. *Science Education*, *29*(3), 119-123.

diSessa, A. (1983). Phenomenology and the evolution of intuition. In Gentner & Stevens (Ed.), *Mental models*. New Jersey: Lawrence Erlbaum Associates, Publishers.

diSessa, A. (1988). Knowledge in pieces. In G. Forman & P. B. Pufall (Eds.), *Constructivism in the computer age*. New Jersey: Lawrence Erlbaum Associates, Publishers.

Driver, R., & Bell, B. (1986). Students' thinking and the learning of science: A constructivist view. *School Science Review*, *67*(240), 443-456.

Duschl, R. A. (1990). *Restructuring science education*. New York: Teachers College, Columbia University.

Easley, J. A. (1959). The Physical Science Study Committee and educational theory. *Harvard Educational Review*, *59*(1), 4-11.

Eylon, B., Linn, M. (1988). Learning and instruction: An examination of four research perspective in science education. *Review of Educational Research*, *58*(3), 251-301.

Gagne, R. M. (1963). The learning requirements of enquiry. *Journal of Research in Science Teaching*, *1*, 144-153.

Gagne, R. M. (1967). Science - A Process Approach. Commission on Science Education of the AAAS.

Gentner, D., & Gentner, R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner, & A. L. Stevens (Eds.), *Mental models*. New Jersey: Lawrence Erlbaum Associates, Publishers.

Harlen, W. (1978). Does content matter in primary science? *School Science Review*, *59*, 614-625.

Harlen, W. (1992). *The teaching of science*. London: David Fulton Publishers.

Hawkins, D. (1965). Messing about in science. *Science and Children*, *2*(5), 5-9.

Hewitt, P. G. (1990), Conceptually speaking. *The Science Teacher*, *57*(5), 54-57.

Hodson, D. (1985). Philosophy of science, science, and science education. *Studies in Science Education*, *12*, 25-57.

Krug, E. A. (1960). *The secondary school curriculum.* New York: Harper & Brothers.

Livermore, A. H. (1964). The process approach of the AAAS Commission on Science Education. *Journal of Research in Science Education*, *2*(4), 271-282.

McAnarney, H. (1972). What is the place of product and process in the development of generalisations in elementary school science? *Science Education*, *56*(1), 85-88.

Norman, D. A. (1983). Some observations on mental models. In D. Gentner & A. L. Stevens (Ed.), *Mental models*. (pp. 7-14). Hillsdale, NJ: Lawrence Erlbaum Associates.

Novick, S., & Nussbaum, J. (1981). Pupil's understanding of the particulate nature of matter: A cross-age study. *Science Education*, *65*(2), 187-196.

Osborne, R. J., & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Education*, *20*(9), 825-838.

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education*, *67*(4), 489-508.

Piaget, J. (1973). *To understand is to invent*. New York: Crossman Publishers.

Pode, J. S. F. (1966). CBA and CHEM-study: An appreciation. *Journal of Chemical Education*, *43*(1), 94-98.

Popper, K. R. (1972). *Objective knowledge*. Oxford: The Clarendon Press.

Robinson, J. T. (1968). *The nature of science and science teaching*. California: Wadsworth Publishing Company.

Ross, S. D. (1971). *The scientific process*. Netherlands: Marituus Nijnoff.

SAPA. (1966). *Grade teacher*, *83*(5), 59-79, 113.

Stake, R. E., & Easley, J. A. (1978). *Case studies in science education* (Vol. 2). Washington, D. C.: U. S. Government Printing Office.

Stinner, A. O. (1992). Science text-books and science teaching: From logic to evidence. *Science Education*, *76*(1), 1-16.

Tasker, R. (1981). Children's view and classroom experience. *The Australian Science Teachers' Journal*, *27*(3), 33-37.

Welch, W. W. (1979). Twenty Years of science curriculum development: A look back. *Review of Research in Education*, *7*, 282-306.

Welch, W. W., Klopfer, L. E., Aikenhead, G. S., & Robinson, J. T. (1981). The role of inquiry in science education: Analysis and recommendations. *Science Education*, *65*(1), 33-50.

Wheeler, A. E., & Kass, H. (1978). Student misconceptions in chemical equilibrium. *Science Education*, *62*(2), 223-232.

White, B. Y. (1988). *Thinker Tools: Causal models, conceptual change, and science education*. The National Science Foundation.

Wilson, G. (1937). *Great men of science*. New York: Garden City Publishing Company, Inc.