ISBN: 978-81-941567-9-6
January 3-6, 2020

NATURE OF SCIENCE: EMBEDDING SCHOOL SCIENCE IN ITS EPISTEMOLOGICAL PERSPECTIVES

Ajeet Rai, Shailendra Kumar
Faculty of Education (K), Banaras Hindu University
ajeetrai04@gmail.com, shailphysics@gmail.com

Nature of science as an educational goal and as an essential component of scientific literacy encompasses explicit development of an informed understanding of the interrelationship between the product and process aspects of science by embedding science teaching and learning in its epistemological bases. Several justifications underpin the spurt in advocacy for inclusion of the 'nature of science' as a cognitive educational outcome and representing the same in a science curriculum. This article presents a synoptic view of the meaning assigned to the term nature of science and henceforth it presents a review of the justifications offered for its inclusion in the science curriculum. Finally, the school science curriculum and the curriculum guidelines for science education at the school level are introspected with the nature of science as an educational goal.

INTRODUCTION

Scientific knowledge along with its practical ramifications in the form of technology has occupied an unprecedented place in the overall history of human civilization and has significantly contributed towards the development of a global culture. UNESCO justifiably emphasizes the development of scientific and technological literacy as is evident in its Project 2000+ Declaration. The significance of science and technological literacy is unanimously acknowledged with the wider social reverberations of the same in the present scenario (Jenkins, 1994). The phenomenal change eventually justifies the concern for achieving some level of understanding of science by the citizenry.

Scientific literacy (SL) has in the recent decades emerged as the primary goal of science education under the auspices of the contemporary reform movement advocating science education for every child (AAAS, 1993; Lee, 97) within a social and cultural context of the child and widespread acceptance of constructivist learning paradigm (AAAS, 93; Staver, 1998) with an overall aim to diffuse SL among all individuals.

SCIENTIFIC LITERACY AND NATURE OF SCIENCE

SL is a widely acknowledged educational goal and at the same time it is also considered as a contested term. Laugksch (2000) claimed that there are different interest groups related to the concept of scientific literacy that interpret the meaning of the term in accordance with their specific interests and purposes. Laugksch classifies the definitions of scientific literacy into three broad categories. The first category

includes definitions that justify SL for the intellectual value associated with the term and highlights the significance of SL for its own intellectual sake rather than some instrumental purpose. SL is also defined in terms of the acquisition of certain context-free basic skills that help them understand science and its methods. Finally, SL is defined in terms of the application of the knowledge and skills in science in the social context and hence bringing in a humanistic perspective in the conceptualization of scientific literacy. The usefulness of being scientifically literate in a different social and cultural arena of life is the guiding perspective of those affiliated to this category. The third perspective on the meaning of SL is used as the general context for discussions about the Nature of Science (NOS).

The social and cultural perspective on defining SL is considered as instrumental in everyday decision-making situations of everyday social life particularly those related to science (National Research Council, 1996). NRC (1996) interprets SL as the minimum understanding required for "personal decision making, participation in civic and cultural affairs and economic productivity" (p.22). Such decision making capabilities are considered as the core of democratic citizenship. Adopting a similar perspective, OECD/PISA defined scientific literacy as "...the capacity to use scientific knowledge, to identify questions and to draw evidence based conclusions to understand and make decisions about the natural world and the changes made to it through human activity" (Gilbert, 2004, p.40). Thus SL is conceptually linked with education for a democratic citizenship.

The social and cultural perspective of SL is a multidimensional concept and it includes Nature of Science (NOS) as one of its essential components beside understanding the content in science and the processes of science. NOS refers to the set of values, assumptions and limitations regarding the scientific knowledge and scientific processes and hence is conceptually linked to the epistemology of science. Attainment of the goal of scientific literacy is then, an outcome of the concerted interaction of the three aspects of science education in the school science experiences. All three aspects are equally important in any curricula of science education that aims to foster scientific literacy among the students.

UNDERSTANDING NATURE OF SCIENCE

NOS is a common phrase used by the science educators' community as a description of the characteristics of science and hence is conceptually related to the philosophy of science in general and more specifically with the epistemology of science, even though the sociologists of science, historians of science and the scientists also have their interests in NOS (Mc Comas. 1998). A common issue transcending across all the interest groups is the conception of the epistemological underpinnings of science- the basic premises that justifies and validates scientific knowledge. With respect to the epistemological base of science, there exists at least two different positions viz. the ontological position of realism and that of anti-realism. The realists conceive nature as having an independent existence with respect to human perceptions and that such independent reality can be cognized in an absolute sense through the methods of science. The science curricula therefore ought to reflect this objective and empirical characteristic of science.

However it is the representation of science in school curriculum that has been questioned in light of the

epistemological underpinnings of science. The traditional science curricula represent scientific knowledge as an exact description of things as they exists in reality that was made known by the disinterested and objective outlook of the scientists who provide conclusive verifications of their ideas through direct observation of nature aided by experimentation. Such science curriculum is grossly misrepresented. Von Glasersfeld (1995) claimed that the realists stand on the truthfulness of reality cannot be logically established as "the truth of any particular piece of knowledge" need comparison with that which is being known which again is logically not possible as it will involve yet 'another act of knowing"(p.6).

The criticism raised against naïve realism caused the alternative epistemological perspective gained currency (Leach, et., al., 1996). The alternative perspective on NOS that emerged and gained importance is commonly termed as the constructivist perspective with an instrumentalist ontology (Matthews, 1998). Constructivist perspective is fundamentally an empiricist in its approach (Staver, 1998) as knowledge is not a simple matter of discovery and verification and rather it is a matter of construction wherein an individual engaged in cognition tries to make out a sense of his sensory impressions. Thus, there exists overlap between the different stands on the NOS. The constructivist perspective on NOS then advocates for a different stand on representation of NOS in science curriculum.

It is owing to the degree of sophistication involved in discussions centered on NOS and the complexity involved therein, that many consider NOS as inaccessible for the school level students and hence make it devoid of its educational sheen (Abd-El-Khallick et al, 1998). However, the contention regarding NOS are basically related to the issues related to ontological positions vis a vis science. However, there are common grounds as well that provide promising prospects for NOS as an educational outcomes. The consensus view that emerged on the NOS is considered as all - philosophers, historians of science, scientists and science educators (Mc Comas, 1998). For example, Matthews (1998) draws the common ground between realists and constructivists and highlights that both acknowledge the changing nature of scientific theories, based on empirical evidences and the research agenda of the scientists are socially and culturally influenced. The existence of common grounds unambiguously makes teaching and learning of Nature of Science feasible and practical.

NATURE OF SCIENCE: CONSENSUS VIEW

Researchers have tried to arrive at a consensus view on NOS that is the best compromise of the different positions held by the philosophers' with respect to NOS and that is relevant for the young students (Bell et al, 2003). NOS is defined in a pedagogically relevant way as the "*values and underlying assumptions …intrinsic to scientific knowledge including the influences and limitations that result from science as a human endeavor* (Schwartz et al 2004, p611). This definition of NOS is pedagogically represented in form of a set of agreed upon 'tenets' (Efflin, et.al., 1999) and enable comprehending science as a body of knowledge as well as a process to arrive at the knowledge (NRC, 1996; Duschl et.al., 1990; Hodson, 1998; Aikenhead & Ryan, 1992). These tenets are listed as below: Science is an attempt to explain natural phenomena; Scientific knowledge is obtained through scientific inquiry that includes both observation and inference; Observations are basically theory laden i.e. what is observed and how it is to be observed is guided by the scientists' theory/

hypotheses; Inferences drawn from the verifiable data is subjective in nature and there are possibilities of disagreement among scientists; Science yields knowledge that is verifiable being justified by observation, experimental evidence, rational arguments and skepticism; The nature of observation and inference in scientific process explains role of creativity in science; Laws and Theories, as the product of science, are related but different from each other and serve different roles in science; Scientific Knowledge while durable has a tentative character. Science has a social and cultural dimension; Science and technology are interrelated but not the same (McComas, 1998; NRC, 1996; Abd-El-Khallick, 1998).

NOS AND CURRICULAR SHIFT

Nature of science is a vital learning outcome that establishes the link between science content knowledge and the processes of science. Advocacy for NOS as an educational outcome has sound theoretical and practical bases. NOS is also construed as the epistemological beliefs (EB) in context of scientific knowledge, where epistemological beliefs relates to what one believes regarding the nature of knowledge and its development (Hofer and Pintrich, 1997) that has been established to be developed among young adolescents as well (Schommer,1993). Further, studies have established that sophistication of the epistemological beliefs is related to the way one processes information and the value one places on that knowledge (Hofer and Pintrich, 1997; Perry, 1970; Carey et al, 1989). NOS being science epistemological beliefs, influences one's way of processing scientific knowledge and applying it in different contexts (Songer & Linn, 1991; Staver, 1998). It also influences one's orientation towards learning of science (Songer and Linn, 1991; Lederman, 1992; Tsai, 1998), enhance students' interest in science (Mc.Comas, 1998) and assist them in reflecting on knowledge content (Larochelle and Desautels, 1991). The way in which students understand NOS influences their conceptual understanding of science content knowledge (Songer and Linn, 1991; Staver, 1998) and reflecting on knowledge content (Larochelle and Desautels, 1991).

Further, understanding of NOS is essential to understand the way scientific knowledge is created along with its limitations. Such an understanding is deemed essential for democratic participation of citizens in social issues particularly those related to science. The ever increasing nexus between social issues and their conceptual link with science and technology is an indication of the even greater significance that will be gained by the concept of NOS. Shamos (1995), while qualifying the importance of NOS, emphasized on defining scientific literacy overwhelmingly in terms of understanding of NOS rather than in terms of content knowledge (quoted by Laugksch, 2000). Millar and Osborn (1998), in their important document *Beyond 2000,* maintains that for a majority of students who are future citizens in different roles rather than future scientists, the core school science curriculum should be one that focuses on *knowledge about* science rather than *knowledge in* science where knowledge about science exclusively includes an understanding of NOS. Thus, *science for citizenship* aims at developing the citizens' capabilities to actively participate in debates and discussions related to such socio-scientific issues (AAS, 1989, Driver et al, 1996, Jenkins, 1999). However, the extent of participation and the quality of decision in such issues depend on the individuals' understanding of the scientific enterprise (Kang et al, 2004; Sadler, 2004) thereby substantiating the salience of NOS to citizenship education.

Summarily it can be claimed that NOS is pedagogically represented as set of cognitive learning outcomes that need to be provided proper representation in science curriculum at the school level. As the cultural context provides the necessary tools for the individuals in the meaning making process (Vygotsky, 1962), the norms and values of science as a culture need to be exhibited before the students (Driver, 1994, p.6).

Almost all the major curricular reforms in the second half of the twentieth century held the Armstrong's assumption that the students will understand the NOS through different science process skills, science content knowledge and scientific inquiry. The major curricular reforms such as Biological Science Curriculum Studies (BSCS), Nuffield Physics, and Physical Science Curriculum Studies (PSCS) laid a greater emphasis on the process aspect of science with the assumption that it will help students learn the true NOS.

However, the implicit approach to develop NOS among students came under severe criticism by the dawn of the twentieth century giving way to more vocal arguments in favor of teaching NOS in an explicit way. Millar and Driver (1987) highlighted the myth of dichotomous view on NOS as content and process and concluded that both the content and the processes of science are intertwined and interdependent for the learners. The study related to NOS and BSCS gave a severe blow to this basic assumption when it was concluded that even a science curriculum with emphasis on the process aspect of science like BSCS failed to develop informed understanding of NOS among the students (Meichtry, 1992) that further supported similar views presented earlier (Lederman, 1992; Abd-El-Khallick & Lederman, 2000).

Currently, diverse contexts are being explored to provide overt teaching and learning of NOS. Scientific Inquiry is still the most favorable and popular context, however in a different form with more emphasis on students active engagement stimulating their thought processes, explored by the researchers for developing informed understanding of NOS (Bianchini & Colburn,2000; Schwartz, et., al., 2001). Historical development of scientific knowledge is also researched for its efficacy in explicitly teaching the NOS principles and has been reported to be a suitable pedagogical approach (Abd-el-Khallick, 1998). Recently, socio-scientific issues are being explored as a pedagogical innovation for explicit discussion on assumptions of science (Sadler, et., al., 2004). Finally, modification in the science text books are also recommended to include overtly expressed section on NOS (McComas, 2003).

NATURE OF SCIENCE AND SCIENCE CURRICULUM: REFLECTIONS ON INDIAN CONTEXT

A brief but relevant understanding of NOS is acknowledged by the curriculum frameworks in Indian context (NCF, 2005) that in turn reflects the emphasis laid on including instructions pertaining to NOS earlier in the academic career (Kang, et. al., 2004). It is justifiably claimed that the link between the science content, science processes and NOS must be overtly made apparent by the teachers and that the "assessment of student`s prior knowledge" related to NOS must be used in the curriculum development (Meichtry, 1992, p. 405). NCERT (1998) in its National Curriculum Guidelines of Syllabus has identified NOS a long back as one of the seven dimensions of science curriculum that was again reiterated NCF (2005). It explicitly states that "Good Science Education is true to child, true to life and true to science" (NCF, 2005,

p.46). Science curriculum can be true to science if it presents a true image of science in the classroom and true to 'life` if the image thus created in the classroom enable the individual, to apply and use that knowledge in real life context including the socio-cultural context.

Unfortunately, the pedagogical approaches to NOS are missing from these documents that reflect their implicit approach towards this educational goal. A closer inspection of the curriculum documents reflect that the pedagogical approach lingers around the process or inquiry approach that unfortunately has yet to be translated into effective classroom practices. It will not be an exaggeration to claim that the curricular approach in vogue for science education is apt to exclude the attainment of vital components of scientific literacy.

The curricular documents grossly failed to explicate exactly what is to be understood by NOS and how to incorporate the same in classroom teaching and learning (Rai, 2009). The scenario raises skepticism with respect to achievement of the goals of NOS. The spurt in advocacy for curricular and instructional modifications with the aim to develop informed understanding of NOS among the students, observed across several nations, should find a place in the concerns of the curriculum policy framers and science educators along with exploration of the innovations (as mentioned in the previous section) in the Indian context. Empirical studies related to NOS could be broadly classified into five categories or encompassing five different themes viz. those related to students' conceptions of the NOS; teachers' conception of NOS; assessment of NOS and interventions; relationships between teachers' conceptions of NOS, classroom practice, and students conception of NOS; and development and validation of instruments for assessment of NOS (Lederman, 1992). Studies are needed in each of these areas as well as a rich empirical database on students' existing framework of knowledge regarding NOS (Kang, Scharmann, & Noh, 2004) is direly needed in the Indian context.

The ambiguity with respect to teaching and learning of NOS in the curriculum frameworks developed from time to time, paucity of empirical studies related to understanding of NOS by the school going students and the instructional strategies related to teaching and learning of the same, neglect of the different principles of NOS in the reputed science text books together manifests the need to rethink about the status of school science vis-à-vis international trend.

REFERENCES

Abd-El-Khallick, F. (1998). The influence of history of science course on student's conceptions of the nature of science. Unpublished doctoral dissertation, Oregon State University, Oregon.

Aikenhead, G.S., & Ryan, A. (1992) 'The development of a new instrument: "Views on Science-Technology-Society" (VOSTS). *Science Education, (76),* 477-491

American Association for the Advancement of Science (1993). *Benchmark for Scientific Literacy*, New York: Oxford University Press.

Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1989). An experiment is when you try it and see if

it works‘: A study of grade seven students‘ understanding of the construction of scientific knowledge. *International Journal of Science Education, 11,* 514-529.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). Young pupils images of science. Philadelphia: Open University Press.

Driver, R. (1994) *Making sense of secondary science*. London: Routledge Falmer.

Duschl, R. A., & Hamilton, R., & Greudy, R. (1990). Psychology and epistemology: Match or mismatch when applied to science education, *International Journal of Science Education, 12*, 230-243

Efflin, J.T., Glennan,S.& Reisch, G.(1999). The Nature of Science: A perspective from the philosophy of Science. *Journal of Research in Science Teaching, 3(6*), 107-116.

Gilbert, J. K. (2004). Models and Modeling: Routes to More Authentic Science Education. *International Journal of Science and Mathematics Education,* 2 (2), 115–130.

Jenkins, E.W. (1999). School science, citizenship and the public understanding of science, *International journal of Science Education, 21(7),* 703-710.

Hodson, D. (1998). Towards a philosophically more valid science curriculum. *Science Education,* 72, 19-40.

Hofer, B.K., & Pintrich, P.R.(1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67(1),* 88-140.

Kang, S., Scharmann, L.C., & Noh, T. (2004). Examining students‘ views on the nature of science: Results from Korean 6th, 8th, and 10th graders. *Science Education, 89,* 314-334.

Laugksch (2000). Scientific Literacy: A conceptual overview, *Science Education,84(1),* pp.71-94.

Larochelle, M., & Desautels, J. (1991). ‘Of course, its just obvious‘: Adolescents ideas of scientific knowledge. *International Journal of Science Education,* 13, 373-389.

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

Lee, O. (1997). Scientific literacy for all: What is it, and how can we achieve it?,. *Journal of Research in Science Teaching, 84(3),* pp. 219-222.

Matthews, M.R. (1998). In Defense of Modest Goals for Teaching About the Nature of Science, *Journal of Research in Science Teaching* 35(2), 161-174.

Millar, R. & Driver, R. (1987). Beyond processes, *Studies in Science Education,*14, pp. 33–62.

McComas, W. (2003). A Textbook Case of the Nature of Science: Laws and Theories in the Science of Biology, *International Journal of Science and Mathematics Education,* 1 (2), 141-155

McComas, W. F., Ed. (1998). *The nature of science in science education.* Science and Technology Education

Library. Philadelphia: Kluwer Academic Publishers.

Meichtry, Y. J. (1992) Influencing students understanding of Nature of Science: Data from a case of curriculum development. *Journal of Research in Science Teaching,* 29, 389-407.

Millar, R., & Osborne, J. F. (Eds.). (1998). *Beyond 2000: Science Education for the Future*. London: King's College London.

National Curriculum Framework (2005): Position paper on science education, New Delhi: NCERT

National Research Council (1996). *National Science Education Standards.* Washington, DC, National Academy Press.

Perry, W. G. (1970). Forms of Intellectual and Ethical Development in the College Years. New York: Holt Rinehart and Winston Inc.

Sadler, Troy D. (2004). Students' Conceptualization of NOS in response to Socio-scientific Issues. *International Journal of Science Education. 26,* 387-409.

Rai, A. K. (2009). Students' understanding of nature of science: An exploration, Unpublished thesis, Faculty of Education, Banaras Hindu University, India.

Ryan, A. G. & Aikenhead, G.S. (1992). Students' preconceptions about the epistemology of science. *Science Education, 76,* 559-580.

Schommer, M. (1993). Epistemological developments and academic performance among secondary students. *Journal of Educational Psychology, 85,* 406-411.

Schwartz, R. S., Ledernan, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: Am explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88,* 610-645.

Songer, N.B., & Linn, M.C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching, 28,* 761-784.

Staver, J.R. (1998). Constructivism: Sound theory for explicating the practice of science and science teaching. *Journal of Research in Science Teaching, 35,* 501-520.

Shamos, M. (1995). *The myth of scientific literacy*, Rutgers Univeristy Press: New Brunswick.

Tsai, C.C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education, 82,* 473-489.

von Glasersfeld, E. (1995). A Constructivist Approach To Teaching', in L. Steffe and J. Gale (eds.), *Constructivism In Education,* pp. 3-16, Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Vygotsky, L.S. (1962). *Thought and Language*, MIT Press: Cambridge.