Science Education and Nature of Science: A Review with Reference to Indian Context

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The purposes and goals of science education is a pressing issue before the science education community. The dependence and interrelatedness of science and society provide a new dynamics to the goals of science education. With changing demands of society the goals need to be reviewed and redefined. Scientific literacy has emerged as the ultimate goal of science education, and, it has incorporated Nature of Science (NOS) as an essential and inevitable dimension of scientific literacy. Consequently several nations have included the goal of NOS with justification in their education policy statements and in curricular guidelines. The present paper provides a review of the importance attached to the NOS as an educational outcome, discusses the same vis a vis the policy and the curricular guidelines for school education in Indian context and presents a review of research related to NOS in Indian context.

Keywords: Nature of Science, Science education, Scientific literacy, Indian context

Introduction

Scientific knowledge as an outcome of the scientific enterprise has proved itself as one of the most important outcomes of human endeavours that led to unprecedented changes and developments in the socio-economic and socio-cultural arena of human civilization. Technology, as a practical ramification of doing science is yet another important development in the history of human civilization. Scientific knowledge and technology together have thus come to occupy an unchallenged significance in the history of human achievements. The impact of science and technology on society and their inter-relationship logically culminated in the recognition of the importance of science as an essential component of school curriculum, yet, the science education interest groups, are persistently encountering the pressing question regarding the purposes of science education particularly so at the school level. What should the science curriculum at the school level strive for and consequently what are the basic guiding forces for the science education to thrive upon? Beside the consideration of the nature of child and the context in which science education is to materialize, the goals for science education to achieve and the practical representations of the goals for science education are thus, the basic questions that guide the science curricula and science education at the school level. The purposes of science education are determined to a large extent on the application and the context of application of scientific knowledge in future.

The growing intricacy between science and society has undoubtedly established a wide range of contexts, including the social contexts for the application of scientific knowledge. Science has crept out in the public arena where people in different social roles have to deal with science and its ramifications. Thus there is a growing concern over making our citizens scientifically literate in that they are not only able to know the various products of science but more importantly they are able to understand science itself. With scientific literacy as the ultimate goal of science education and keeping in view the variegated context in which scientific knowledge and processes are applicable, there is an all pervasive emphasis placed on the development of the relevant understanding regarding the epistemological bases of science. The epistemology of science in brief form has attained the status of a cognitive educational outcome in itself, whether our students are taught to prepare them for future citizenship or to enable them to enter the arena of higher education in science. There exist sound sociological, philosophical and psychological grounds that establish the NOS as an educationally important outcome for the students. The importance of this aspect of science further gets reflected in the National Curriculum Framework-NCF, (NCERT, 2005) although with different wordings.

Grounded in the foregoing discussion, the present paper presents a review of the importance of situating the teaching and learning of science in its epistemological base and the vitality of developing different instructional procedures to help students understand the limitations and assumptions of scientific knowledge and scientific processes, i.e., the NOS. The paper further presents a synoptic view of school science education with respect to students and teachers and their

understanding of the epistemological base of science. Finally the concluding section of the paper discusses the status of research related to students' and teachers' understanding of the epistemology of science.

Scientific Literacy: Goal of Science Education

The impact of science and technology on society, their interrelationship and the emerging social contexts for the application of knowledge logically culminated in the recognition of scientific literacy as the ultimate goal of science education. Recently UNESCO emphasized the development of scientific and technological literacy through its Project 2000 Declaration, wherein scientific and technology literacy is considered important for every individual and for all nations (Jenkins, 1994). The scientific literacy movement professes science education for every child (AAAS, 1993; Lee, 1997), adopting a social and contextual approach and a constructivist learning paradigm (AAAS, 1989; 1993), enabling and ennobling the individual into the scientifically oriented social life.

OECD/PISA defined scientific literacy as

> *"...the capacity to use scientific knowledge, to identify questions and to draw evidence based conclusions in order to understand and make decisions about the natural world and the changes made to it through human activity" (Gilbert, 2004, p. 40).*

Scientific literacy is a common term that denotes a group of interrelated educational outcomes that describe the aims of contemporary science education reforms. There are various interpretations of scientific literacy with different researchers emphasizing on different dimensions of scientific literacy (DeBoer, 1991). One of the important outcomes underlined by almost all the definitions of scientific literacy is the knowledge and understanding of epistemology of science, popularly termed as NOS.

Epistemology of Science

Science is a human endeavour to explore, to understand and to predict nature and its variegated phenomena. The result of this endeavour is both a description of the natural events as well as the explanation of the same. The description and explanations are presented by the scientists in the form of different facts, laws, models and theories that provides the basic structure to the discipline of science. The scientists effort to understand nature is further characterized by the different ways in which they conduct their investigation and that provides a dynamic aspect to science where the different processes through which the scientific knowledge is established is sometimes seen as even more important and significant than the knowledge produced itself. It is invariably termed as the process aspect of science. However, besides the product and process aspect of science, NOS of science is the third, very important, aspect of science that has significant pedagogical value and that cannot be overlooked.

NOS refer to the characteristics of science itself. It is a description of the values and assumptions that demarcate scientific knowledge and the scientific process from other disciplines. It is also referred to as the knowledge about science (Millar & Osborne, 1998 as quoted by Bennett, 2003). NOS is a term commonly used in the educational circle to include the different constructs that are used to describe the basic epistemological bases of science – its knowledge as well as its processes. It refers to those characteristics of science that primarily helps in differentiating science from non-science and in identifying the basic premises on which scientific knowledge is built upon. A comprehensive definition of NOS, proposed by McComas, is:

> *"The nature of science is a fertile hybrid arena which blends aspects of various social studies of science including the history, sociology, philosophy of science combined with research from cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours" (McComas, 1998, p. 4-5).*

The trend has however been to present NOS in terms of different aspects or tenets of science that together provide a description or rather a model of NOS. He further claimed that misconceptions exist related to these aspects of science among the teachers and the students. Several other authors have also provided their list of such tenets about NOS sharing commonality with the description provided by McComas (1998). The common tenets or aspects of NOS are as: tentativeness of scientific knowledge; science relies on empirical evidence; scientific knowledge is subjective in nature; imagination has a significant role in development of scientific knowledge; difference and relationship between observation and inference; difference and relationship between scientific theories and laws; There is no one method of science that is the universal method of science; science and technology are different although interrelated. (AAAS, 1989; Abd-el-Khallick, Bell, & Lederman 1998; Lederman, Abd-el-Khallick, Bell, & Schwartz, 2002; McComas, 1998).

The list of tenets is various and without an understanding of these basic epistemological premises of science it seems difficult for individuals to truly understand science and its ways.

Nature of Science: Why Bother About it?

Scientific literacy as a common term implies the inclusion of NOS as an important educational outcome. There are several arguments favouring the inclusion of NOS as an important

dimension of scientific literacy. Science education reform movements in the contemporary era have two major concerns of 'accessibility' and 'relevance' (Bennett, 2003). Whereas accessibility is concerned with the access of science education to every student, the issue of relevance is concerned with reforming of science education in a way that it enables the individual in applying what he has learned through school science experiences. Psychologists related to research in the area of epistemological beliefs have established that an individual's epistemological beliefs about knowledge influence the way that individual applies the knowledge (Driver, Leach, Millar, & Scott, 1996). Consequently, how an individual will apply scientific knowledge is influenced by the individual's science epistemological beliefs. The argument thus favours the inclusion of NOS as an important dimension of scientific literacy.

The second argument is grounded in the social context for the application of science related knowledge and understanding. Science, in the present era, has crept into the arena of public discourse and decisions. This is not a negation of the importance of the expertise of the scientists in their domain of knowledge. Rather the contention is that given the close interdependence between science and society on the one hand and the growing dependency of society on science has brought the citizenry to the extent where it is inevitable for them to have a minimum level of knowledge and understanding of science that enables them to participate in science related discourse at least over those issues that are directly linked to them, personally or socially. Many writers use the word 'socio-scientific issues' to mark such science related social issues that demands active participation of citizens (Sadler, 2004). However, whether an individual can discuss such matters and to what extent his/her participation is successful depends on the individual's capacity to understand not only the issue at hand but also on his/her understanding of the NOS. While qualifying the importance of NOS, defining of scientific literacy overwhelmingly in terms of understanding of NOS rather than in terms of content knowledge has been emphasized (Shamos, 1995 as quoted by Laugksch, 2000). Thus, a scientifically literate individual must have an informed understanding of NOS. Further 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 (Millar & Osborne, 1998 in Bennett, 2003).

Another important perspective guiding the contemporary science education reforms, across almost all the nations, is the constructivists' theory of learning. This philosophy of learning known popularly as constructivism claims that the students build or construct their understanding of new ideas instead of acquiring it from outside in some readymade form. Learning, from an experience, is not a linear process and the prior experiences play a vital role in interpreting new situations (Miami Museum of Science, 2001). Constructivist philosophy is grounded in Piaget's cognitive and developmental perspective, Vygotsky's interactional and cultural perspectives and Dewey's educational philosophy. Dewey proposes that learning is active in nature and it takes place through experience. Experience involves the learners' active engagement and manipulation of some environmental stimuli and adapting their behaviour accordingly. Similarly, Piaget emphasized that knowledge is essentially constructed and assimilation and accommodation are important processes in the construction of knowledge by the learners. Vygotsky's social cognition theory emphasized that the cultural context including the family environment has a stimulating effect on the learners' process of knowledge construction, and every individual is a constructor of his/her own knowledge. Similarly, the social environment and the cultural and family values of the individual influence how one assigns a meaning to any new information or idea.

Epistemological beliefs relates to one's beliefs regarding knowledge and its development (Hofer & Pintrich, 1997). The beliefs however develop in a socio-cultural milieu, thereby establishing a relevance for the constructivists paradigm. Adopting the constructivist perspective it was claimed that, "Learners need to be given access not only to physical experiences but also to the concepts and models of science [Nature of Science]" (Driver, 1994, p. 6). The claim refers to the acknowledgement of the importance of cultural values along with the environment in the meaning making process. Thus it seems inevitable that students are given opportunities to comprehend the values of science and to understand the characteristics of scientific culture that will help in the application of scientific knowledge by individuals in different contexts including the social context. The emphasis on individual knowledge construction and the subjectivity in science with respect to drawing inferences, the emphasis on social negotiation and the establishment of science through a common agreement between the experts in science are some of the examples of close correspondence between science and the basic assumptions of social constructivism. Thus the social constructivists approach to teach science provides a useful context for students to develop understanding of NOS. The foregoing discussion substantiates the significance of NOS as an educational outcome.

Thus the perspectives of relevance, preparation for citizenship and learning theories all contribute towards justifying the significance of NOS as an educational outcome. Further, the structure of educational system in India includes a ten year general schooling system that compulsorily includes science. A majority of the students who complete their ten year school education opt out of the pipeline for higher education in science. Thus for a majority of the students the school science experiences are the basic experiences that will continue with

them throughout their life shaping their knowledge and understanding of science. It is further recognized that the student as a responsible member of the society in future has to deal with several social issues related to science. For example the environmental issues are social issues closely related to science. However society at many times faces differing views from scientists with respect to some particular environmental issue such as global warming. The members of the society are required to take an informed decision in such cases or at least must find themselves capable of understanding the possibility of differing inferences. Similar situations, also arises often with respect to agricultural and health issues.

Curricular Guidelines and Nature of Science: International and National Perspective

Even though the advocacy for developing an understanding of NOS among the students is an important education goal, there still exist gross misconceptions related to what science is, how scientists work, what are the bases of scientific claims etc. The over-dominance of the process-product approach is infested with an unintentional but grossly mistaken assumption with respect to NOS, particularly owing to the significance attached to only the process skills of science along with the content knowledge and with the assumption that the students will understand NOS through such classroom activities (Lederman, et al., 2002). The fallacy of the assumption is evident with the data from studies conducted on students with respect to their understanding of NOS (Miechtry, 1992). As a result there has been an increasing demand for explicit linking of the relationship between science content knowledge, science processes and the NOS in the classroom.

The significance of NOS as an important educational outcome has been endorsed by several nations through their educational policy statements, giving a new impetus to empirical studies related to students and teachers understanding of NOS and highlighting the variegated instructional approaches to develop students' conceptions about science and its ways. However the situation is not the same in the national context. The Education Commission of 1964 has highlighted the need of developing spirit of scientific inquiry among students, further endorsed by the National Policy on Education of 1992. The consequence was seen as the inclusion of laboratory experiences as a necessary part of the school science experiences. There exists, nevertheless, doubt as to what extent the students can develop that 'true spirit of inquiry' if they are not able to understand the basic characteristics of science itself. The issue therefore needs proper attention and consequent inclusion in the curricular guidelines framed for the development of spirit of scientific inquiry.

However even the much acclaimed Hoshangabad Science Teaching Programme faced the criticism of not dealing with the issues of NOS through its curricular innovations that nevertheless highlighted the process aspect of science. Similarly the NCF, 2005 considered the development of the epistemological bases of science but has left out the important issue of incorporating the same as the educational outcome within its framework of science curricular guidelines. The curricular framework lacks any explicit mention of NOS as an educational outcome and hence the absence of any definite guidelines with respect to teaching of NOS is noticeable and needs attention at the apex level. The existing focus, as per the NCF 2005 position paper on science education, the curriculum framework suggested is one with a balance between the science process skills and science content knowledge, following student centred pedagogy embedded within the constructivists paradigm towards science teaching and learning. Thus it seems implausible that the guidelines provided by NCF is of some relevance with respect to teaching and learning about the character of science and its processes.

There exists, undoubtedly a need to revisit and rethink science curriculum from the perspective of attaining informed understanding of NOS. It requires overt linking of the science content, science processes and NOS by teachers in their day to day classroom procedures (Miechty, 1992). However the situation is even more complicated in developing countries like ours where the school and the teachers have to come up with overcrowded students on the one hand and paucity of resources on the other hand. The strategies such as emphasis on strict inquiry approach might not be a feasible one in our context. One of the best possible means suggested is to look for a possible way in the text books that include separate treatment of the different scientists and the brief outline given regarding the development of scientific knowledge. The section can be modified and developed in a way that better explicates the various tenets of NOS. The text book revision however needs to be supplemented by the necessary training for the teachers, both at pre-service as well as at the in-service level, to focus on such topics and to include them in the overall evaluation scheme at least so within the framework of internal evaluation system.

Another important suggestion made is to capitalize on the emphasis laid by NCF, 2005 on the extra-curricular experiences in science. Under this category a relevant module, including some science related socially relevant issue that highlights the various aspects of NOS, can be created and used for the students at the secondary stage. However the suggestion being made is still in the hypothetical stage and it needs further deliberations and analysis to develop the idea into a practically feasible and pedagogically relevant means to develop appropriate understanding of NOS. Nevertheless other possibilities can also be explored.

Researches Related to Nature of Science: Indian Context

Empirical studies provide the required information base to reform curricula and to design instructional strategies relevant for teaching and learning of NOS. The attempt to modify the textbooks or the curricular provisions or the development of the idea of creating a module related to NOS need to be based on an understanding of the students existing knowledge framework with respect to NOS (Kang, Scharmann, & Noh, 2004). Further, empirical evidences regarding the teachers' views on the possible means and problems in teaching the various aspects of NOS are also required for making any attempt of change (Lederman, 1999). Such studies, in the Indian context are random and sporadic in nature. A review of the literature related to science education research revealed only a few intermittent studies and with a focus on the status of students knowledge regarding the various aspects of NOS (Masih, 1995; Sood, 1978). The paucity of empirical studies in the Indian context related to NOS is suggestive of the knowledge gap related to pedagogical aspects of NOS and the gap need to be filled.

Conclusion

A true science curriculum stands for representing the comprehensive view regarding science in the classroom. Further the science curriculum can be true to 'life` if the image thus created in the classroom enable the individual, to apply and use the knowledge in real life context. A true representation of science then requires focus on all the different aspects of science, including NOS. Consequently, the core school science curriculum should be one that focuses equally on knowledge in science as well as knowledge about science, particularly so when a majority of the school leaving students enter different disciplines and vocational streams after their 10 years of school education.

An understanding of the epistemological bases of science in a brief but relevant form can play a significant role in the application of scientific knowledge in the social context. However, NOS, is overlooked from the pedagogical point of view in the Indian context. Rather, it will not be an exaggeration to state that there exists a very low level of awareness regarding the significance of NOS as is evident from the scarcity of the empirical studies on the pedagogical aspects of teaching NOS in the Indian context. The belief that NOS is an affective outcome, attained by students rather as a by-product of science learning, is still prevalent and needs to be discarded in favour of accepting NOS as a relevant and useful educational outcome. The textbooks and the extra-curricular activities in science can be some of the promising explicit avenues to incorporate NOS, within the school science curriculum. However accepting something as a vital educational outcome, is easier to say than the translation of the same pedagogically to suit the context. There is need of a rich data base through empirical investigations related to NOS. Such empirical studies, in particular, should include the teachers' general understanding of NOS and their beliefs regarding teaching of the same as well as the students' existing knowledge base regarding the different aspects of NOS. It's only through such empirically derived data-base that any meaningful and effective decisions could be taken regarding inclusion of the same in the curricular framework and regarding the strategies of teaching NOS that is feasible in the diverse classroom contexts in India.

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