Research Trends in Nature of Science
Analysis and Implications

MAMTA SINGHAL*

Abstract

It's been more than 100 years now since the term 'Nature of Science (NOS)' is being emphasised in the field of science education. Central Association of Science and Mathematics Teachers advocated NOS as an important goal for studying science as early as 1907. Science education reform documents worldwide such as Science for All Americans (AAAS, 1990), Benchmarks for Science Literacy (AAAS, 1993) and National Curriculum Framework (NCF-2005) suggest NOS as an important educational outcome. National Science Teachers Association, NSTA (1982) regarded understanding NOS as one of the critical components of scientific literacy. In such a scenario, the research in this area also has to be on the priority. The focus of the research has been different areas ranging from developing assessment tool on NOS, evaluating students' and teachers' understanding to studying the impact of curriculum and instruction. The early research in this area has been confined to measuring students' attitudes, interest or ability to engage in the process of science. Gradually the focus of the research shifted to epistemological conception of nature of science, that is, science as a way of knowing, values and beliefs inherent to scientific knowledge and its development. With this focus the instruments designed to measure the nature of science became more open ended. This paper presents an overview of several emerging research trends on Nature of Science.

* *Assistant Professor*, Institute of Home Economics, University of Delhi.

Introduction

In the field of science education and pedagogy, Nature of Science (NOS) is an emerging and significant area of research. Researchers and scholars have defined NOS in several ways. During the early 1900's the Nature of Science was equivalent to knowledge of concepts, laws and theories in science. The focus shifted to scientific method and process skill in the 1960's. More recently, nature of science has been associated with the epistemological view of science. Nature of Science (NOS) typically refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992). Similarly, McComas (1998) points out that, the Nature of Science (NOS) is a fertile hybrid arena which blends aspects of various social studies of science including history, sociology and 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 endeavors. Recognising the complex and multifaceted nature of science, an attempt has been made to delineate some common characteristics of NOS that could be used by the researchers, teachers, educators and policy makers in their attempts to develop assessment tools and emphasise NOS in science education. Some of these aspects being tentativeness, laws, vs., theory, subjectivity, imagination and creativity, social and cultural embeddedness, etc. There may be some other aspects which some researchers may include or exclude in the list but more or less the term NOS acquired some consensus about its meaning. In this paper the author has discussed several research trends in the area of Nature of Science and their implications for education. The three main focus areas of research have been as given below.

- Research on development of tools and instruments
- Research on students and teachers' perception of NOS
- Research on curriculum and instruction about NOS

Research on Development of Tools and Instruments

Considering the importance of understanding NOS by the educationist and curriculum makers all over the world, a need was felt to assess the level of understanding NOS among students and teachers. Various tools and instruments have been developed over past few decades to assess students and teachers' conception of NOS. The first formal assessments done in 1960's were mostly quantitative, and various instruments were developed by researchers that could easily grade or quantify the students' and teachers' understanding. Such a trend was more common till mid 1980's.

However, some open-ended questions formed a part of discussions related to construction and validation of test items. More recently, there has been a greater emphasis on getting an in-depth view of understanding NOS. This has resulted in more open-ended probes about NOS. Many of the earlier attempts to assess NOS have focused on assessing science process skills, attitudes and interest thereby limiting the scope and meaning of Nature of Science.

Lederman (2007) points out that the validity of many of these instruments is questionable. One of the first instruments,Test on Understanding Science (TOUS) (Cooley and Klopfer, 1961) consisted of the four-alternative 60-item multiple choice test that can be scored with an "overall" or "general" score as well as three subscale scores (I) understanding about the scientific enterprise; (II) the scientist; (III) the methods and aims of science. The instrument was reasonably good choice at the time it was developed, but later studies have suggested that it is not a good measure of nature of science as some items of TOUS evoke a response of attitude and conveys obscure meaning. Wiscons in Inventory of Science processes (Scientific Literacy Research Center,1967) was criticised for its length and long time required for administration. Also, while scoring the option of inaccurate and not-understood are combined to mean as opposite of accurate. The instrument does not have any sub-scales and therefore the respondents' only get a unitary score. However, Lederman (2007) reported that the inventory was one of the widely used instruments after TOUS in that time. Science Process Inventory (SPI) by Welch (1967) consisted of 135 two-choice (agree-disagree) items. Items cover perceptions of the role of scientists, the nature and functions of theories, underlying assumptions made by scientists, and other aspects of the scientific process. The test is suitable for high school students and adults. The long length, having only forced choice items and no subscales were some of the shortcomings of SPI. Nature of Science Scale (NOSS) developed by Kimball (1968) consisted of Likert type statements where the respondents get a score of 2 for agree, 1 for neutral and 0 for disagree. The scale was deemed suitable for scientists, teachers and educators but not for high school students. The lack of subscales restricted the scales ability to gauge differentiated understanding of NOS on various dimensions. Rubba (1977) developed another instrument called Nature of Scientific Knowledge Scale (NSKS) which had 48 statements in Likert five-point response format which can be divided in six subscale-amoral, creative, developmental, parsimonious, testable and unified. Despite some overlaps among the subscales, overall, the scale has been viewed positively by the research community. Lederman

(2007) warns of some concern about the face validity of the instrument. Some items in the subscales are identical except that they are worded negatively. Conceptions of Scientific Theories Test (COST) developed by (Cotham and Smith, 1981) tested several aspects of NOS but was biased in placing a high emphasis on the tentativeness of scientific theories as compared to other dimensions. Another significant test called Views on Science–Technology-Society (VOST) by Aikenhead, Fleming and Ryan (1987) had 114 multiple choice items on various issues related to science–technology and society. The test is unique in the sense that the respondents do not get a numeric score for their choice; rather the respondents have to generate an argumentative paragraph to defend their position. The test has been widely used in many researches concerning STS issues. Views of Nature of Science (VNOS-A) developed by Lederman and O, Malley (1990) is an open-ended survey consisting of seven items primarily focused on the tentativeness of science. The test was supposed to be used in conjugation with the follow-up interviews. The interviews helped to clarify the responses on the paper and pencil test. Certain problems were later noted by the authors as the responses of the paper pencil test indicated that the respondents had difficulty in comprehending the questions. The later forms (VNOS-B, C, D, and E) were developed by other researchers for specific groups. VNOS-B and VNOS-C are very lengthy with respondents taking about 90 minutes to complete the test. VNOS-D was developed to reduce the time taken by previous forms and was expected to produce similar results. VNOS-E was developed for very young students (K-3). The items can also be used for students who cannot read or write. A modified form of NSKS instrument Modified Nature of Scientific Knowledge Scale (MNSKS) was developed by Meichtry (1992). The test is simplified for use with 6^{th}, 7^{th} and 8^{th} grade students. Nott and Wellington (1995) used critical Incidents tests consisting of a series of critical incidents closely related to classroom and requires the teachers to answer questions such as—what would you do; what could you do and what should you do, in such situations. The test has been criticised as the teachers' responses may or may not be related to their views about NOS. Views of Science and Education Questionnaire (VOSE) by Chen (2006) is designed to measure participants' concepts of the Nature of Science (NOS) and relevant teaching attitudes on a five-point scale. The test was validated on college students and was most suitable to teacher educators, pre-service and in-service teachers as it also measures participants' attitude towards teaching NOS. Students Understanding of Science and Scientific Inquiry (SUSSI) developed by Ling L. Liang, Sufen Chen Xian Chen, Osman Nafiz Kaya, April Dean Adams, Monica Macklin and Jazlin Ebenezer (2008) blends Likert type items with related open ended questions to assess subjects' views on nature of science. The instrument is quantitative as well as qualitative and that provides the opportunity to look at inconsistencies in the participants views on likert type items and qualitative items. This is very useful feature of the test. Several other instruments like NOSI-E, The Nature of Science Instrument Elementary (NOSI-E) by Shelgah, P. (2012) based on Rasch Principles is another instrument to assess understanding of NOS among participants.

The researches done on development of instruments have demonstrated that there is a continuous attempt to improve the validity of instruments. Some of the earlier instruments used in 1960s for assessing NOS have been criticised for having a poor validity as they often ended up measuring attitudes, skills or abilities in science instead of NOS conceptions. The instruments in 1980's addressed this issue by focusing on the most commonly identified aspects of NOS. However, most of these instruments included forced choice items such as agree or disagree, Likert type or multiple choice items. Lederman and O' Malley (1990) criticised these test for carrying developers' views and biases. The assumption that the respondents perceive and interpret the items in a similar manner as the developer is problematic. The instruments also ended up labeling the respondents as informed or un-informed type categories based on a numerical score. However, what numerical score was adequate for a particular category was questionable. These instruments did not focus on the reasons for making a particular choice. Also, even though almost all students believed scientific knowledge is tentative, the underlying reasons were very different. If one did not assess the underlying reasons, the analysis would be very superficial to reveal participants' conceptions of NOS.

NOS studies after the late 1980s shifted from being more quantitative to more qualitative in nature, utilising more flexible tools such as the Images of Science Probe (Driver, Leach, Millar and Scott, 1996); Small Group Discussion (Solomon,1992); Situated-Inquiry Interviews (Ryder, Leach and Driver, 1999; Welzel and Roth, 1998). Besides, the studies also utilised reviews of lesson plans and documents; field observations of classrooms and teachers; concept maps; and case studies for assessing NOS. These studies, however, had their own limitations. The tools such as interviews, group discussions and concept maps required longer time to administer and hence were not feasible for large scale studies. Also, the interpretations of detailed responses on questionnaires and interviews tended to be subjective and hence reliability became a concern in these studies. The possibility of the respondents being influenced by the researcher's point of view in a face-to-face interaction cannot be ruled out. To overcome the shortcoming of purely quantitative or qualitative assessment, a more recent trend has been to use both the forms for data collection. The findings can then be triangulated to ensure better reliability.

Research on Students' and Teachers' Conceptions of NOS

Assessing the students' and teachers' understanding of Nature of Science has been the main concern of researchers in the field of science education. Some researchers' have also attempted to explore scientist's (those involved in the scientific research) understanding of NOS. This paper describes some research trends in this this area in the last two decades. The studies have examined students and teachers' conceptions of nature of science in different disciplines of science, teachers teaching at different levels, students in various grades with respect to role of gender, cross cultural comparisons and impact of instruction, etc. Kim and Nehm (2011) did the the cross-cultural comparison of Korean and American science teachers' views of evolution and the nature of science. The study compared Korean and American science teachers' understandings of evolution and nature of science and acceptance of evolution in order to elucidate how knowledge and belief relationships are manifested in different cultural contexts. It was found that Korean science teachers exhibited 'moderate' evolutionary acceptance levels comparable to or lower than American science teacher samples. Gender was significantly related to Korean teachers' evolution content knowledge and acceptance of evolution. Liang, Chen S., Chen, X., Kaya, O.N., Adams, A.D., Macklin, M. and Ebenezer, J. (2009) investigated pre-service teachers' views on the nature of scientific knowledge development with respect to six elements: observations and inferences, tentativeness, scientific theories and laws, social and cultural embeddedness, creativity and imagination, and scientific methods in an international collaborative study. A total of 640 pre-service teachers, 209 from the United States, and 212 from China, and 219 from Turkey, participated in the study. Across the three countries, the participants demonstrated better understanding of the tentative aspect of NOS but less understanding of the nature of and relationship between scientific theories and scientific laws. The Chinese sample scored highest on five of the six Likert subscales, the USA sample demonstrated more informed views on observation and inference, and the Turkish pre-service teachers possessed relatively more traditional views in all six NOS aspects. Dogan and Abd-El-Khalick (2008) assessed grade 10 Turkish students' and science teachers' conceptions of nature of science (NOS) and whether these conceptions were related to selected variables. These variables included participants' gender, geographical region, and the Socioeconomic Status (SES) of their city and region; teacher disciplinary background, years of teaching experience, graduate degree, and type of teacher training program; and student household SES and parents' educational level. Teacher views were mostly similar to those of their students. Teacher and student views of some NOS aspects were related to some of the target variables. These included teachers' graduate degree and geographical region; and student household SES, parents' education, and SES of their city and geographical region. The relationship between student NOS views and enhanced economic and educational capitals of their households, as well as the SES status of their cities and geographical regions pointed to significant cultural (specifically Western) and intellectual underpinnings of understandings about NOS. In another study about students' conceptions, Dagher, Brickhouse, Shipman and Letts (2004) explored college students' representations about the nature of theories during their enrolment in an astronomy course with instruction designed to address a number of Nature of Science issues. This study suggested the need to explicitly address the nature of proof in science and issues of tentativeness and certainty students' associate with scientific theories, and provide students with more opportunities to utilise the language of science. Some studies also explored participants' conceptions of 'scientists'. Reis and Galvão (2004) found that socio-scientific controversies and the way science and scientists were depicted in the media, seemed to have produced some impact on students' conceptions about scientists.

Rubin, Bar and Cohen (2003) investigated the image of scientists held by Israeli pre-service teachers, the majority of whom were female. The population consisted of students belonging to two cultures, Hebrew-speaking and Arabic-speaking. It was found that the image of the scientist is perceived as predominantly male, a physicist or a chemist, working in a laboratory typical of the eighteenth, nineteenth or the early-twentieth century. Students did not differentiate between scientists and inventors. Different images were held in the two cultures. Most of the Arabic-speaking students put Classical Islamic scientists near the top of their lists and thought of the scientist as an Arab male, while the Hebrew speaking students' was as a typical Western male. The interplay between participants' socio-cultural beliefs and conceptions of nature of science was illustrated by Liu and Lederman (2002) in their study where they explored the relationship, if any, between an individual's culturally based worldviews and conceptions of Nature of Science among 54 Taiwanese prospective science teachers. Moss (2001) examined pre-college students' understandings of the Nature of Science and tracked those beliefs over the course of an academic year. The study was conducted in a semi-rural school of North East US. The study distinguished between Nature of scientific knowledge and nature of scientific enterprise. Students held more complete understandings of the nature of scientific knowledge than the nature of the scientific enterprise. Their conceptions remained mostly unchanged over the year despite their participation in the project-based, hands-on science course.

Although, in this paper the author has only quoted few researches done in the more recent years, there are numerous other studies that have attempted to study students and teachers' conceptions of Nature of science. While the earlier studies involved quantitative measures, the later ones used more qualitative measures. Regardless of the assessment approach used, there are some general trends from the researches. Students at all levels including middle school, high school or college level have inadequate conceptions on various aspects of Nature of science. The most informed views are about the tentativeness of science, whereas the least informed views are indicated about the distinction between laws and theories. Studies with the primary level students are very few. The studies that compared students' and teachers' have also indicated that the teacher's understanding is not better than the students' understanding. Also, the teachers' views about NOS do not necessarily affect students' views. This may be because the teachers do not make an attempt to explicitly teach NOS or use strategies that help in developing better understanding of NOS. Language, religion and gender have emerged as significant factors related to the understanding of NOS. However, the causal relationship of these factors with NOS understanding needs to be more systematically and deeply probed.

Trends from Review of researches on curriculum, textbooks and impact of instruction

The inadequate conceptions of students' and teachers' about NOS and the constant emphasis of curriculum reform documents led the researchers to develop and implement curricula and instructions designed to enhance NOS understanding. The first such attempt was made by Klopfer and Cooley (1963). He designed the first curriculum called History of Science Cases (HOSC) for high schools. The researchers proposed that using cases from History of Science in the curriculum would help in developing a better understanding of NOS. The study conducted on a large sample of students from various disciplines (physics, chemistry and biology) showed significant improvement in the post-test score of treatment group using TOUS (Lederman, 1992). Several curriculum research projects of 1960's such as Physical Science

Study Curriculum (PSSC), Biological Science Curriculum Study (BSCS) showed enhanced understanding of NOS in different studies by Crumb (1961) and Yager and Wick (1966). These curricula used laboratory centered approaches besides paying specific attention to historical development of major concepts and principles in science. Aikenhead (1979) developed a curriculum titled "Science as a way of knowing" that emphasised that the nature, process and social aspect of science through a variety of inquiry skills and focus on science-technology-society interactions. The curriculum showed positive response with grade 11 and 12 students.

Not all studies however showed the positive impact of curriculum specifically designed to address NOS. The studies by Troxel (1968) and Jungwirth (1970) as cited in Lederman (1992) showed that there is no significant difference between the pre-test and post-test scores used to see the effectiveness of CHEM, CBA and BSCS curricula respectively.

The influence of the teachers' views on classroom practices or student's views was explored by several studies in 1980s. There is research supporting a direct influence on classroom practice (Brickhouse, 1989, 1990; Gallagher, 1991) as well as the position that there is no influence (Duschl and Wright, 1989). The interaction with teachers' showed that the administrative constraints, infrastructure, level of students and various other factors influence the translation of teachers' belief into practice. Bell, Lederman, and Abd-El-Khalick (2000) reported the factors that mediate translation of nature of science into practice as articulated by the participants (pre-service teachers) were (a) perceiving the nature of science as less significant than other outcomes, such as science content and processes (b) concern for students' needs and attitudes, and (c) preoccupation with classroom management and routine chores (d) discomfort with understandings of the nature of science (e) lack of resources and experience for teaching and assessing understandings of the nature of science, and constraints specific to student teaching. The result of the investigation by Lederman (1999) involving five high school biology teachers showed that although the teachers possessed informed views of NOS, there classroom practices were not directly affected by their views. Their students did not learn NOS as there was no explicit attempt to do so. Therefore, one cannot assume that an improved understanding of NOS among teachers would influence students' understanding in a positive manner.

With such studies there has been a shift in the research involving more explicit instructional approaches. Palmquist and Finley (1997) reported pre-service teachers understanding of NOS in a teaching program using contemporary teaching strategies, such as conceptual change and co-operative learning. The direct teaching about NOS aspects was very little. Similar findings are reported by Abd-El-Khalick (2001) in his study on prospective teachers. The use of explicit reflective approach to teach NOS resulted in significant improvement in the NOS aspects including tentative, empirically based, theory laden, inferential, imaginative and creative characteristics of scientific knowledge. Abell, Martini and George (2001) targeted several aspects of NOS in a moon investigation. The students learnt that scientists make observations and generate patterns but they did not realise that observation could precede or follow the development of a theory. Students were able to articulate the several aspects of NOS but they did not see the connection between what they learned and the scientific community. The researchers recognised the importance of being explicit for improving NOS understanding among participants. Abd-El-Khalick (2005) reported the positive impact of Philosophy of Science Course along with the methods course for prospective science teachers whereas Kim and Irving (2010) indicated the positive impact of contextual examples from history science while teaching genetics on the targeted aspects of NOS. The results of most of these studies have shown positive impact of explicit instruction about NOS aspects. The focus is however not on the traditional mode of citing examples from the history of science but on the use of reflective inquiry-oriented approaches.

Conclusion

The earlier researches on NOS focused on measuring NOS using Likert scale type of items. These items pertained to measuring the attitudes, skills or interest in science but the epistemological aspect of science were often neglected. Many of these instruments have been criticised for poor validity. Another concern with the use of these instruments has been the inherent bias in the interpretation of scores or the written response. There have been significant discrepancies between the written responses of the students or teachers on a particular test and the responses that were given during interviews. The instruments with more open–ended items that helped to assess a deeper understanding of NOS. Also, there have been attempts to supplement the quantitative assessment with qualitative assessment so that more valid conclusions about participants understanding can be drawn. An interest in developing instruments or tools to assess NOS has led to more clear articulation of nature of science. For instance, most researchers now agree to some common aspects such as law vs. theory, social and cultural influence, creativity and imagination. Scientific method, etc., as important dimensions of NOS. However, the researchers have also mentioned the flexibility in these aspects.

Students and teachers at all levels have shown lack of NOS understanding with respect to various dimensions of NOS. Many of these instruments were commonly used for students and teachers and have indicated similar results both for students and teachers. A few researchers have also indicated the influence of academic qualification, experience and socio -economic status of teachers on their NOS understanding. However, the correlation between understanding of NOS and any of these factors is not well established. Explicit curriculum and instruction related to NOS helps in developing better understanding of NOS. However, the focus should be on reflective, inquiry oriented, conceptual change approaches for NOS instruction rather than merely citing examples from history of science.

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