TENTATIVENESS OF SCIENTIFIC THEORY: WHAT DO HIGH SCHOOL STUDENTS BELIEVE

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Nature of Science (NOS) is an important component of scientific literacy and as such is considered as significant for school going children. A minimum level of understanding of the character of science is considered as essential for all students to make them scientifically literate. One of the principles included within the broader concept of NOS is that scientific knowledge including scientific theories are tentative in nature and that the scientific theories are more a creation of the scientists' rather than mere discoveries. This paper presents the findings related to school student's beliefs and their justifications regarding tentative nature and constructed versus discovered nature of scientific theories. The findings from this qualitative study suggest naïve understanding of nature of scientific theories among the participants. It is also suggestive of need for initiatives to enhance students' understanding of nature of science.

INTRODUCTION

Scientific literacy is considered as important for every individual and for all nations and school education has a key role in achieving the goal of scientific literacy for all and Nature of Science (NOS) is unanimously considered as a vital component of scientific literacy (AAAS, 1993; NRC, 1996; Lederman et al., 2002; Bell, et al., 2003; NCF, 2005).

NOS reflects the epistemological beliefs inherent to scientific knowledge and its development and refers to the description of the values and assumptions underlying science and scientific process, understanding of which is supposed to influence the way individual applies scientific knowledge (Driver et al., 1996), facilitates students` understanding of science content knowledge (McComas, 1998), their ability to effectively deal with socio- scientific issues (Kolsto, 2001) and in intelligently interpreting popular science reports (Norris & Phillips, 1994). The school science curriculum is, therefore, expected to cater to the needs of the majority of the students along with the need to prepare individuals for career as future scientists. National Curriculum Framework (2005) also acknowledges that understanding of NOS is an important goal of science education.

NOS, however, is a contested term that has been defined differently by different people. Mc Comas (1998) defined NOS comprehensively including the sociological, philosophical and cognitive perspectives into the definition. A more general and practical definition given by Lederman et al., (2002), defined NOS in terms of the values, assumptions and limitations of scientific knowledge. Irrespective of the contest in defining NOS at a higher level, there is a considerable degree of agreement among the different stakeholders regarding the different principles that are included in the umbrella term of NOS and that are important as well as comprehensible by school going children (Lederman et al., 2002). One of the significant principles of NOS is that scientific theories (ST) are tentative in nature although they are reliable to a great extent (McComas, 1998; Abd-El-Khallick, et al., 1998). STs are considered as the ultimate goal of science that provides the explanatory and predictive powers to science. It is accepted to be a scientists' construction and that further modification or changes are not untenable in future. Several studies have been conducted to ascertain the students understanding of the scientific theories as absolute or tentative and whether it is discovered or constructed in nature.

However, no empirical study was located in the Indian context that investigates and explored the school going students' views on different aspects of NOS in general and the tentative versus absolute and discovered versus constructed nature of scientific theories in particular. The observation was considered as significant on the ground that school science curriculum includes learning of several scientific theories and that exploring students' views will provide insight into any effort to develop informed understanding of NOS among the students. The present study was thus carried out to answer the following research question: *What are the students views regarding nature of scientific theories and what justifications are held by the students' in favour of their views?*

METHOD

In accordance to the purpose of the study a qualitative approach was used to answer the research questions.

Participants

The participants for the exploratory study were science students in first year of their two year precollege course in science stream. Twenty-eight students, with high achievement in science at the secondary level, from four schools in the city of Varanasi affiliated to Central Board of Secondary Education were purposively identified as participants for the present study. All the schools used a mixed language approach for instruction and followed the text-books prescribed by NCERT during their secondary level education.

Data Collection

Data collection method involved collection of written response on a Science Reflection Questionnaire (comprising of six open-ended questions) as well as semi-structured interview data in accordance to the procedure detailed by Creswell (2003) and as advocated for by the previous research studies (Lederman & O`Malley, 1990). All the data were collected during the first quarter of 2008.

Credibility and trustworthiness of the data was established through member check method (Lincoln & Guba, 1985) and through triangulation of data from the questionnaire and from the interviews (Denzin, 1970). Finally, Scott's pi estimate of inter-coder reliability was calculated involving two independent coders and was found to be 0.82 which was considered as satisfactory (Shoemaker, 2003).

Data Analysis

The qualitative study followed inductive data analysis procedure (Creswell, 2004) that implies an iterative process for identifying patterns in response and for categorization and coding of the data. The entire data from questionnaire and semi-structured interviews were analyzed to identify explicit notations pertaining to nature of scientific theories. These identified notations were then inductively analyzed to identify students' reason or justification and categorize the same.

FINDINGS OF THE STUDY

The findings of the present study are presented as follows:

Finding 1

The entire twenty eight student in the present study accepted that scientific theories are discovered in nature. However, the only fourteen students were able to provide any reason or justification in support of their belief thus reflecting understanding of any sort, naïve or sophisticated.

A majority of the students (n=11) believed that the changes and/or modifications in STs are due to the **technological advancements**. Advances in technology leads to more sophisticated observations that leads to discovery of new facts and henceforth caused change in existing theory. The following transcript from the students' interview is exhibitive of their views:

> Interviewer: You believe that scientific theories can change. What reason do you have to think so?
>
> Vijay: Many of the theories can change …. In past the scientist lack in Technology and scientist's give theory by what they can see and they can know. But modern day technology helps in better instruments to see and observe.
>
> Interviewer: You have cited Rutherford in your written response to support your belief. Can you explain that in light of what you said here?
>
> Vijay: Rutherford experiment gave a new atomic structure…….he made an experiment [that was possible] because he had sophisticated instruments to do his experiment.

Similarly another student used the lessons from biology class and presented the discovery of microscopes as a technological advancement that led to new knowledge in science and yet another student cited the invention of telescopes as the reason behind change in scientists' ideas and theories. Thus these students believed that development of technology helps the scientists to know many new things that were earlier unknown and that technological advancement in science lead to development of more sophisticated instruments that enabled the scientists to do experiments at a much more sophisticated level. Thus, the scientists come to know of several facts/evidences/ideas that were unknown earlier. The new facts that scientists comes to know with the help of new technology causes the scientists` to change many of their ideas and theories.

Three of the students discussed about the mismatch between the theory and observation as the leading force behind the change in scientific theories or ideas and also included the role of technological advancements in theory change in their discussion. This subset of three students believed that scientists` develop explanations for different things. However, when the existing explanations do not apply to several of the observed facts, the scientists` try to study the phenomenon with alternative thinking and come up with new explanations that can explain the observed facts. One student explained in her written response that *often the old theories are proved wrong….. they do not support many facts and scientists do more experiments to make a theory and show other facts as true.* Further these students were also able to cite examples from their science classrooms to explain their views. The context of atomic structure was cited by two of the students whereas one student cited the context of Lamarck's theory. One of this subset of students expressed that *Rutherford did not agree with Thomson and proved him wrong…He gave a new model that showed why alpha particle was deflected in the Rutherford experiment*. These students also used the justification of technological advancement as a reason for change and modification in scientific ideas.

Thus only these three students clearly understood the explanation function of science and were able to synthesize the idea of new observations and facts leading to deficiency in the explanatory power of ST and thereby leading to modification or change in ST.

Finding 2

Of the 28 students five students believed in the constructed nature of ST, whereas seven (7) students believed that STs are discovered and sixteen (16) students were unable to discuss the issue at all. The students affiliated with the construction view believed that science explains natural phenomena and many times the scientists creativity is important in coming up with an explanation of those phenomena. They further believed that the scientists need to be creative and imaginative while developing their theories. One of the student explained in his written response that *when the scientist observed the vapours coming out he must have been very creative and tried to link different things together…that the energy of this vapour can be used to develop an engine….so I think that scientific theories are created more so.. S*imilar explanations were also provided by other students commonly drawing their reasons from the works of Newton, Priestly and Rutherford. The reasons provided by the students reflected their informed understanding with respect to scientific theories in comparison to other students.

Seven of the students believed that scientific theories are discovered rather than constructed. The scientists try to uncover the facts and relationships that are already there, existing in nature. Thus one student believing in the discovered nature of scientific theories wrote that *"scientists work for truth and truth is always there in nature. Scientist work and they discover it...like the laws of reflection was already there but scientist first gave the two laws"*. However these seven students do not outright reject the role of creativity in science. They believed that scientists are highly creative. However, while explaining creativity in science the students commonly cited the case of technological inventions where the creativity is important. For example one of the participant wrote that [*scientist] also use their Imagination and Creativity at many times in making new things for the society.* The following transcript reflects the students' views on creativity of scientists in science:

Interviewer: You have explained that scientists are creative. Can you please cite some relevant example to support your view?

Swati: Scientist invent when something new is given by him… we say that airplane was invented and bulb was invented by Addison because they used their imagination to develop so many new things.

The rest of the students (sixteen) did not comment on the constructed or discovered nature of scientific theories. However they all agreed that creativity is important in science and at the same time delimiting the role in case of technological inventions. Thus, the analysis of students' written response and interview data revealed that a majority of students' views on the nature of scientific theories (with respect to discovered vs absolutist dimension) are far from being sophisticated. Thus, they could not extrapolate their understanding of imagination and creativity to the different theories. They believed that all the theories are about the natural phenomenon that already exists in nature and the scientists search for them. Therefore, they find out or discover the theories.

The pattern of students' response further illustrates their lack of understanding about theory and it`s difference from other scientific knowledge (scientific law in particular) as was evident from the frequent mention of different laws and facts in place of theories in their response.

For instance at many occasions they cited different laws, (such as law of reflection), in their monologues related to scientific theories assuming that both kind of scientific knowledge are same.

DISCUSSION OF FINDINGS

No exploratory study could be identified in the Indian context for comparison and discussion. However, the findings from the present study were not in contradiction to the findings reported by different researchers across the globe. Perhaps the misconceptions regarding different aspects of NOS, including those related to ST has a globally common pattern. The present study revealed that a majority of the participants of this study could hardly discuss their position with respect to the different aspects of nature of ST. The students believed that the tentativeness of ST were mainly due to the discovery of new facts and evidences. They also frequently mentioned of the betterment of technology as the leading factor behind the discovery of new facts and evidences. Similar finding was reported by several researchers in different countries (Kang, et al., 2004; Solomon et al., 1996).

Another significant finding of the study was that a majority of the students could not discuss at all about the invented vs discovered nature of scientific theories. Among those who responded on this aspect, a majority of them accepted that ST is discovered rather than invented or created by the scientists. Such beliefs are a clear indication of the students' inability to associate the scientists' imagination and creativity with other aspects of development of scientific knowledge. Such finding is not an exception since great significance is attached with the word 'discover' in the studies of students epistemological beliefs (Larochelle & Desautels, 1991). The high frequency of students adhering to the belief that ST discovered implies that these students have no understanding of the explanatory nature of science. Rather the students exhibit an understanding that centres around the idea that science is description of natural events or phenomenon. The majority of the students failed to realize that the imagined and created ideas are integral part of the scientists' effort to develop scientific theories and laws. Similar findings were reported by Tsai (1998) wherein he concluded that students, both having dynamic view regarding tentative nature of scientific knowledge as well as having a static view, considered ST as discovered rather than invented. Literature on students' understanding of NOS suggests that early adolescents find it difficult to identify creation of explanations and their subsequent testing, as central to science (Solomon et al., 1994; Carey et al., 1989). Thus although the subjects of this study mentioned about imagination and creativity with respect to Newton they failed to identify the created nature of ST.

CONCLUDING REMARKS

The conclusions of the present study could be inferred as an iteration of the conclusion made by the researchers a long back that students come to the classroom with naïve epistemologies (Grosslight et al., 1991). The novelty of the study lies in the fact that it is embedded in a new context. One of the major conclusion of the present study was that a majority of the students were in possession of naïve understanding of nature of scientific theories since they failed to comprehend the explanatory power as the criteria for success of a ST and believed that it is only emergence of new facts through technological intervention that can cause a theory to change. Further, the student failed to comprehend the constructed nature of ST and hence could not appreciate the role of scientists' creativity and imagination in development of a ST. It was also concluded that the current curriculum of science has many relevant contexts, as was evident from the frequent citation of examples from the text books that can be capitalized to improve upon the students' conception of nature of ST and for that matter of NOS.

Finally, it was concluded that it is the curricular and instructional factors that led to a lack of consistency in students' understanding of NOS thus reiterating the position that naïve understanding of NOSST is not to be attributed to the lack of student potential (Klienman, 1965). There is uncontested need of explicit guidelines on part of national curriculum frameworks, the leading curricular guideline for school science, pertaining to the specific model of NOS that is to be emphasized in our classrooms and the general guidelines for their achievement in the classroom. The students left on their own to link different science content to NOS are all prone to develop such compartmentalized understanding. Thus, the students are required to have an explicit exposure to different experiences that might help them develop a well-connected and coherent understanding of NOS.

Although the nature of the study prevents any generalization beyond the sample, nevertheless it does signify the naïve epistemological development among the learners. At the same time large scale survey is also needed to develop a rich data base pertaining to different alternative conception held by the students with respect to nature of science in India that is inevitably of great importance in guiding curricular modification to incorporate explicit instruction on different aspects of NOS.

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