Undergraduate Science Students' Conceptions of Nature of Science

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Abstract

This study has explored the conceptions of Nature of Science (NOS) of undergraduate science students of University of Delhi, India. The sample consisted of Students of the undergraduate (Hons.) courses in Physics, Chemistry, Botany, Zoology, Microbiology and Biochemistry who have completed at least their first year in college. The data was collected usingStudent Understanding of Science and Scientific Inquiry (SUSSI, 2008) Scale and in-depth interviews. The scale consists of24 Likert type statement divided into 6 categories, each of which depicts a unique aspect of Nature of Science. The scale also has some open- ended questions that allow the participants to explain or give examples to support their views. WhileSUSSI was administered to 180 science students from different colleges, interviews were conducted with 90 of them who had already taken SUSSI. The students' views were classified as 'Informed', 'Transitional' and 'Naïve' on each of the six aspects of NOS. The study indicated a lack of understanding on different aspects of NOS, however the percentage of students belonging to informed category varied for various aspects of NOS

Key Words

Nature of Science (NOS), Undergraduate science students, Informed, Transitional, Naive

Introduction

The place of Nature of Science as an integral component of science education is now well established and is found in the education policy statements of many countries including India (NCF-2000; NCF-2005).Despite the recognition of the need to develop an understanding of NOS, the grass root situation is not very encouraging. Lederman (2007) in his review of studies on Nature of Science suggests poor understanding of various aspects of NOS at all levels. In India, the problem is more severe as there is a scarcity of research in this area. Philosophers, Historians, Scientists and Educators often disagree on the meaning and aspects of Nature of Science. Sometimes the phrase 'History and Philosophy of Science (HSP)' is also used to describe the interplay of disciplines that inform science education and the character of science. However, the phrase 'Nature of Science (NOS)' is more popular in the field of science education. Although there is no precise definition of Nature 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).

The recent curriculum frameworks for school education and teacher education programs in India have witnessed some impact of worldwide science education reforms but the systematic research on students, teachers and curriculum is still lacking. The higher education institutions offering science courses are all the more oblivious of the importance of NOS in their science curricula. Nature of Science is still not recognized as a worthwhile area of research among the research scholars and teachers associated with science courses. A few researches in this area have been done by the research scholars associated with science education or teacher educators. The implications of these researches are also limited to school education and teacher education. The science courses at the undergraduate level often limits themselves to the prescribed content and laboratory experiments. The concerns that relate to Nature of science such as the development of scientific knowledge, nature of laws and theories, social and cultural influence and the ways of inquiry are often neglected. This paper presents the conceptions of Nature of science (NOS) in science students of undergraduate courses.

Research Objective

To explore the Undergraduate Science students' conceptions of Nature of Science with respect to the following Aspects of Nature of Science:

i. Observation vs. Inference
ii. Tentativeness

iii. Laws vs. theory
iv. Social and cultural influence
v. Imagination and creativity
vi. Methodology of scientific investigations.

Design of the Study

The study used a mixed method research design for collecting and analyzing data. The mixed method research design uses both quantitative and qualitative tools for data collection and the results could be derived using the triangulation of quantitative and qualitative data. Thestudy used the following tools for data collection.

(1)Student Understanding of Science and Scientific Inquiry (SUSSI, 2008) Scale:A standard instrument called 'Student Understanding of Science and Scientific Inquiry (SUSSI)' was used for collecting the data.SUSSI was developed by Ling L. Liang, Sufen Chen, Xian Chen, Osman Nafiz Kaya, April Dean Adamas, Monica Macklin and Jazlin Ebenezer; La Salle University, Philadelphia, USA, as a part of the study entitled "Assessing pre-service elementary teachers' views on the Nature of Scientific Knowledge: A dual response instrument" in June 2007 and revised in Jan 2008.The test blends Likert type items with related open- ended questions to assess subjects' views on nature of science. The instrument has both quantitative as well as qualitative aspects. The respondents first select their responses given in the Likert format and then explain what they actually think about nature of science and scientific inquiry by providing examples. A specific question (only one per subscale) is given which the subjects need to explain qualitatively. This helped the researcher to gather preliminary qualitative data about each aspect and also formed the basis for conducting in-depth interviews.

(2) Semi- Structured Interviews: Semi-structured Interviews were conducted with only 50 percent of the sample (total 90 students) to gather qualitative data for each aspect of NOS. The interview schedule with preliminary questions was prepared and focused group interviews in the group of 3-4 students were conducted. Based on the student's responses more and a variety of questions were added during the actual interview. The preliminary interview schedule consisted of the following questions.

1. What factors can affect your/scientists' observation? Can there be differences in observation of same event by different people or at different times.
2. We observe sun to rise in the east and set in the west. However, we all know that sun is stationery and earth move around it. How scientist would have come to this conclusion?
3. What constitutes scientific knowledge? How is scientific knowledge created?
4. How are laws, hypothesis and theory different from each other? Can you explain the process by which a law or theory was established (any example)?
5. How do laws and theories get modified or replaced?
6. Does society and culture influence science, in what ways? Give some examples to support your answer.
7. Who are scientists? Are you or your teacher also scientists? Why/why not?
8. Do you know any contemporary scientists and their work? Are you aware about your teachers' research work?
9. Can scientists be imaginative and creative? Explain/Give some examples.
10. What methods are used by scientists in the field? Are the same methods used in the classroom? Give examples.

These questions belong to all the six aspects of NOS considered under the study.

Sample

A total of 180 students from University of Delhi, who were in the 2nd or 3rd year of the undergraduate science courses participated in the study. Students of the undergraduate (Hons.) courses in Physics, Chemistry, Botany, Zoology, Microbiology and Biochemistry were chosen. The data using SUSSI was collected from all the 180 students. However, the interviews were conducted with 90 of them. The sample was purposive in nature and data was collected based on the easy access of the researcher and willingness of students to participate the research.

Data Collection and Analysis

The data collection and analysis can be categorised in three categories.

(i) Based on Likert Scale Items of SUSSI

The standard instrument called Students' and Teachers' Understanding of Science and Scientific Inquiry (SUSSI) was used by the researcher to collect data in the initial phase. The instrument consists of 24 Likert type items under 6 themes or aspects.These Aspects are:

Aspect 1- Observation and Inference

Both observations and Inference have a distinct role in the development of scientific knowledge. Observations are based on the sensory experiences and they can be subjective. Inferences are interpretations of the observations and multiple interpretations could be possible depending upon the perspective of scientists making those observations. Observations are theory laden and no number of observations (however large) is sufficient to qualify any statement as universal truth. The inferences are drawn as an attempt to explain the observations and multiple inferences could be drawn by the scientists but the ones that are supported with reliable evidence are to be accepted.

Aspect 2- Change of Scientific Theories

One of the most significant aspect of NOS is its tentativeness. Contrary to the traditional view that scientific knowledge is absolute and fixed, the latest notion that scientific knowledge is tentative and dynamic is accepted. Scientific knowledge is durable and the change is slow but there are many examples in history of science to support that existing scientifc knowledge gets modified and sometimes may even be completely replaced.

Aspect 3- Scientific laws vs. Theories

Both laws and theories have their own role in science and both may get modified. Theories emerge as an attempt to explain the natural phenomenon by testing the hypotheses. They could be called well substantiated hypothesis. Laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. The distinction between laws and theories should be maintained. Laws are not theories that have been proven.

Aspect 4- Social and Cultural Influence on Science

Scientific knowledge is influenced by the culture and society. The social structures, religion, political and economic considerations affect the scientists in certain ways. However, the community of practitioners should exhibit openness, curiosity, logical and rational thinking and should practice freedom from bias in all possible manners.

Aspect 5- Imagination and Creativity in Scientific Investigation

The role of imagination and creativity is often undermined in science but scientists need creativity and imagination in almost all their investigations. Scientific pursuit involves problem solving and scientists propose many imaginative and creative ways of defining the problem, inquiring its different aspects and use creative and innovative ways of finding the solution.

Aspect 6- Methodology of Science

There is no single universal step-by-step scientific method that all scientists follow. The traditional view of science heavily relies on experimentation as the method of science. However, it is now well accepted that scientists use a variety of methods in their pursuit of inquiry.

Scoring the Likert type items of SUSSI

The SUSSI instrument used for data collection consisted of 24 Likert type items categorized under 6 themes. Each of these items is marked from SD (strongly disagree) to SA (strongly agree) on a five-point Likert scale.The authors of SUSSI have marked all items as positive or negative in their scoring guidelines. The positive items are scored from 1 (for SD) to 5 (for SA). The negative items are scored from 5 (for SD) to 1 (for SA). For the Likert items, the respondents' views were classified as 'Naïve' views if none of the four responses received a score greater than 3 within each theme. The respondents' views were classified as 'Informed' views if all the four responses received a score greater than 3 within each theme. The remaining views of the respondents that could not be classified as either 'Naïve' or 'Informed' views were classified as 'Transitional' views.

Scoring the open -ended written responses of SUSSI

A scoring guide as given by the authors of SUSSI was used for scoring the open-ended responses. A response was considered as an informed view (score= 3), if it was consistent with contemporary thought on the NOS theme.

The six aspects used by SUSSI are briefly described above and each response was evaluated against the description provided under NOS aspect. Any responses that represented partially informed views or failed to provide reasons for justification of their statements were rated as transitional views (score=2). Responses that involved either misconceptions or self-contradicting statements were rated as naïve views (score=1). Finally, each of the following situations was coded as not classifiable (NC) if: there was no response; they stated that they do not know; the response did not address the prompt; or, the response cannot be classified based on the rubric descriptions.
The table 1 depicts the percentage of students in each category – Naïve, Transitional or Informed based on their scores on the Likert type items of SUSSI

Table 1- Percentage of students in each category based on SUSSI

Category	Aspect 1	Aspect 2	Aspect 3	Aspect 4	Aspect 5	Aspect 6
Naive	33	5	62	50	46	43
Transitiona	51	30	31	34	40	41
Informed	16	65	7	16	14	16

The table indicates that the maximum numbers of students have naïve views of Aspect 3 (Law vs. theory); Aspect 4 (Influence of culture and society); Aspect 5 (Role of imagination and creativity in science) and Aspect 6 (methodology of science). On Aspect 1 (Observation vs. Inference) maximum number of students had transitional views whereas on Aspect 2 (Change of scientific theories) maximum numbers had informed view. The data suggest lack of understanding of NOS among students on most aspects of NOS (under consideration as per SUSSI).

(ii) Based on the written responses of subjective dimension of SUSSI

The qualitative data on students' and teachers understanding of NOS was collected through the written responses on subjective dimension of SUSSI and through the in- depth interviews conducted by the researcher on various aspects of NOS.
The subjective responses on SUSSI required the participants to give examples to support their answers. However, many of them did not give examples or could not explain the example. Quite a few did not respond at all on the subjective dimension or their response did not address the aspect under study. Such responses had to be treated as 'Not Classified'.
The table 2 depicts the data based on written responses on SUSSI which were classified as naïve, transitional or informed using a classification rubric developed by the researcher.

Table 2 Percentage of students in each category based on written responses to SUSSI

Category	Aspect 1	Aspect 2	Aspect 3	Aspect 4	Aspect 5	Aspect 6
Naïve	38	10	52	45	53	32
Transitional	40	38	24	35	28	51
Informed	8	50	5	13	12	10
Not Classified	14	2	19	7	7	7

(iii) Based on the Interviews with students

The researcher conducted interviews on all aspects on NOS in order to gain an in-depth understanding of students' conceptions. These were classified as Naïve(N), Transitional(T) and Informed(I) using the same rubric as used for written responses.
The table 3 presents the percentage of students in each category based on their responses during the interview.

Table 3 Percentage of Teachers in each category based on the interview

Category	Aspect1	Aspect 2	Aspect 3	Aspect 4	Aspect 5	Aspect 6
Naive	35	12	58	48	56	35
Transitional	48	36	35	32	32	46

Informed	17	52	7	20	12	19

For final interpretation, the SUSSI score was assigned a weightage of 40%, written responses on SUSSI a weightage of 20% and the interview responses a weightage of 40%. This classification along with weighted average of percentages provided insights to the researcher and helped in drawinginferences.The written responses were given a comparatively low weightage as the responses of the participants were often very brief and unclear making it difficult for the researcher to put it in a clear category. Also, sometimes the subjective part of SUSSI was left blank or the responses did not address the question. Such responses were treated as not classified and it affected the percentage of participants in other categories. Therefore, the scores on the written responses were treated as less reliable and given less weightage. The interview responses and scores on the Likert type items of SUSSI were given a weightage of 40% each.Table 4 below presents final percentage of students in each category (based on the weighted average responses represented in table1, 2 and 3)

Table 4 Final Percentage of students in each category using weighted averages

tegory	**pect 1**	**pect 2**	**pect 3**	**pect 4**	**pect 5**	**pect 6**
ïve						
ansitional						
ormed						
t Classified						

Qualitative Analysis and Discussion for each Aspect of NOS

Aspect 1 Observation Vs Inference

The maximum number of participants (47%) belonged to 'Transitional' category. The interviews and written responses suggested that although students were aware of the role and importance of observation and inference in science but they often could not distinguish between observation and inference. These participants also believed in the 'objective' view of observation though they said that certain factors may affect the observation. These factors were however not related to scientists' different point of views, their experience or background but were related to the environmental or instrumental factors. Thus, if the environmental conditions were kept the same and the instruments used for observation were working fine, the observations made by different observers would be same. The inference may be same or different as cited by some participants. However, these participants were not able to explain the reason for that. During the interview students mentioned the importance of observation in science. According to many of them observation is the first step of scientific investigation and also held a very important place in their laboratory work. The in-depth probing, however suggested that observation was equated with doing experiments in the laboratories and taking 'Readings' with the help of suitable apparatus. These so-called observations should match the desired theoretical results.

The 35% students who belonged to naïve category believed that observation in science is always precise and accurate. According to them scientists observe very keenly and through sophisticated instruments. They also verify their observation many times so that they cannot go wrong. They equate observation with facts. According to them observation has no relation with the theoretical knowledge, previous experience or background of the observer especially in case of science. Inference was also sometimes treated as the same as observation. For some, inference was the explanation based on observation and only the correct explanation was finally accepted. It seemed that these participants equated inference with theory. These participants had very strong belief in the objectivity of science.The 15% students who belonged to the 'Informed' category appreciated the role as well as limitations of observation in science. They differentiated observation from inference and reflected on how the same observations could be interpreted differently by different people based on previous experience or theoretical knowledge. Some participants gave examples from daily life to explain their point of view.

Aspect 2 – Change of Scientific Knowledge

This is one aspect where maximum number of students (57%) were in the 'Informed' category. The informed views were indicative of participants' beliefs in the tentativeness of scientific knowledge. The reason for the highest number of participants in the informed category on this aspect was because the curricula in all subjects had examples of a previous theory being replaced by the other. Most of them said that the previous theory was found deficient in the light of newer evidence and hence was modified or replaced. Most of them, however did not appreciate the process of change or the social factors that may be related to change. The history of discipline was understood as a series of contributions by different scientists or accumulation of knowledge in the discipline.

The Naïve category had fewer students and teachers (9%) as compared to other aspects. These participants believed scientific knowledge to be universal and based on facts. According to them progress in science was based on newer discoveries and formulation of new theories. The new theories explained those phenomena that were unexplained so far or were not adequately explained. Newer knowledge was viewed as an addition to the previous knowledge. The laws were seen as absolute truths that never change. The theories that had experimental evidence are more like laws and do not change (for example in physics) but the ones that cannot be verified through experiments (in case of biology) can change as they were viewpoints of individual scientists.

Transitional views indicated the awareness of tentativeness in science among participants but they were not sure of the reasons. They sometimes changed their views towards the Naïve category or Informed category depending on the researcher's position during the interviews.

Aspect 3 - Laws vs. Theories

The maximum number of participants (58%) exhibited Naïve views on this aspect. This was despite the fact that the curriculum of all science courses at undergraduate level was full of laws and theories related to that discipline. The interviews with the students revealed that the curriculum only emphasized the content of the law or theory but not how a particular law or theory had been established. Many of them believed that laws were derived from the theories after experimental verification. A vast majority of students believed that laws had higher credibility than theories as theories are tentative. The findings were similar to other studies by Meyling (1997), Dagher and Boujaoude (1997) and Dagheretal (2004). Meyling (1997) in his study explicitly taught epistemology in four Physics courses (Grade 11-13) for two years in order to change students' conception of laws, hypothesis, theories and models in addition to pathways of scientific discoveries. The study indicated that many students believed in a hierarchy of credibility where a hypothesis had a low probability of correctness and a law had the highest probability. In a study of college Biology seniors' understanding of theory in general and evolutionary theory in particular, Dagher and Boujaoude (1997) reported that students implicitly adopted certain characteristics of theory whereby, unless a theory was testable, replicable, or leads to predictions, it was not to be considered scientific or reliable. A number of students in that study used a combination of these characteristics to conclude that the theory of evolution was a very tentative theory, more resembling to a hypothesis. This problematic understanding was attributed partly due to the absence of teaching about the nature of biological theories and encouraged by strong religious beliefs. Dagher et al. (2004) explored the college students' representations about nature of theories during their enrolment in a large astronomy course and found that many of them believed laws as more certain theories. Also the notion that a theory becomes law was quite widespread. Also in agreement with Meyling (1997), the study noted that students perception of tentative character of theories was not founded on epistemological reasons (e.g. the problem of induction) but on deficient experimental evidence.

Aspect 4- Influence of Culture and Society

A very high percentage of students (48%) belonged to Naïve category on this aspect. This showed that objectivity and universality were the most important characteristics of science. During their interviews, most of them agreed that science (more so technology) affected society. However, in terms of society and culture impacting the science, they clearly said that there was hardly any influence. Scientists carried their investigation without any social and cultural influence. They were objective and free from bias. They reported what they observed or found out through their research as anyone can verify that. The percentage of participants in 'Transitional' category was also quite significant. They equated science with technology and believed that science has helped mankind through its various inventions. On probing further, they tended to change their stance sometimes to 'Naïve' or 'Informed' category. For example, one of the students said 'Wheel is the greatest invention of science'. The researcher probed further by asking questions like: 'Who discovered wheel? , Was he a scientist? , Was wheel not a socio- cultural invention? , Were the principles of motion known at that time?' These questions left the student pondering and she said that she had never thought of such aspects in relation to science.

Rei and Galvo (2004) studied the possible impact of recent controversies surrounding scientific and technological issues on the conceptions about the nature of science of a specific group of students (11 grade students). The study found that a lot of students referred to medical and biological themes as socio-scientific issues as these were the themes chosen by the cinema, T.V and newspapers. The students often carried the image portrayed by media about these issues which was often distorted. A high percentage of students (76.2%) claimed to have never approached or discussed any socio-scientific issues in their classes. For these students, school was not a source of information and clarification regarding these issues and that role was fulfilled by the media and family in general. The media also influenced their image of 'scientists' and the work done by them.

In the context of the current study, these finding were very relevant as the relationship between science technology and society was often understood in terms of the contributions of science or technology for curing diseases, nuclear power or environmental concerns. The students however, did not appreciate the role of culture, religion, gender and social structures that might influence the progress of scientific developments in a society.

Aspect 5- Role of Imagination and Creativity in Science

More than 50% students exhibited 'Naïve' views on this particular aspect. In the interviews with students and through their qualitative response on SUSSI, it was found that students believed imagination and creativity to be a hindrance to objectivity and logical thought in science. Science was supposed to produce repeatable and verifiable knowledge which anybody can confirm through testing, it cannot be based on creativity or imagination. This view indicated a strong belief in universal method of science, a method that was based on precise observation, measurement and verification.

A significant number of students had 'Transitional' views who believed that sometimes while making a hypothesis, scientists used their imagination but eventually for verifying that hypothesis they had to use the so called 'scientific process'. Informed views were held by only 13% students. These participants believed that scientists used their imagination and creativity at various steps in various ways. Their view was quite similar to Kuhn's analogy of science as a puzzle solving activity. Just like a puzzle can be looked at differently by different people, have various approaches towards its solution and even the solution may be different in certain cases, science consists of various puzzles needed to solved by different scientists. Therefore, scientists had to use their imagination and creativity in solving these puzzles. However, the most appropriate solution is finally accepted by the scientific community. The acceptance or validation of the solution happens through scientific community that works within a given paradigm. This is the role of society in creating scientific knowledge. Though none of the participants explicitly referred to Kuhn in explaining their point of view but the views seemed to belong to informed category.

Aspect 6-Methodology of Scientific Investigation

A very high percentage of students (45%) exhibited Transitional views on this category. The reason for high number of participants in the transitional category was because participants changed their stands on the different statements mentioned in SUSSI under this aspect. The researcher felt this may be due to the fact that the participants found some statements confusing. However, during the interviews it was revealed that many of them believed that there were different methods in science because in their curriculum the terms method, technique or process were used very frequently. The method here typically meant the process used by a particular scientist for arriving at a particular finding. This represented a very fixed view about the method of science. There was no discussion in the curriculum about how that particular method or process got established. Participants often said that scientists use different methods for their investigations but further probing suggested their emphasis was on experimental method. By different methods, they often meant variation in the experimental methods in terms of equipment used for the same investigation. For example, some students mentioned finding the value of 'g' using Katers pendulum as well as simple pendulum. Some mentioned using different ways of doing salt analysis in Chemistry. The essence of the different methods was, however, verification of the known. On asking whether the teaching learning methods in science were similar to scientists' way of investigation, the answer was mostly 'no'. The reason as cited commonly was that undergraduate science courses were not meant for research. Secondly, scientists discover something new whereas the purpose of science courses was only to know what is already known.

Findings

- The highest percentage of students showed naïve views on the aspect 'Laws vs. theory'. The terms law and theory were the most commonly used terms in the context of science but the distinction between the two was not appreciated by the students as well teachers. Although they may state or explain a particular law and theory, they did not understand how laws and theories are established.
- A significant number of students had informed views on the aspect 'Change of scientific theories. They believed that scientific knowledge was tentative. However, most of them could not appreciate the reasons or the process leading to change of scientific theories. The replacement or modification of a scientific theory was often understood as simply the superiority of one theory (and also the associated scientist) over the other.
- Creativity and imagination were very less associated with science and many students saw these attributes as hindrance to the objectivity and rationality of scientists. Only 13% students exhibited informed views on this dimension.
- The students believed in the superiority of experimental method over other methods in scientific investigation. However, they appreciated that scientists might use different methods in their investigation. The classroom processes seemed to limit their ways of investigation and hence they were not sure of using other methods.
- The students understood the role of observation and inference in development of scientific knowledge but a vast majority of them could not differentiate between the two. Only15% students who belonged to the 'Informed' category appreciated the role as well as limitations of observation in science.
- Overall, the undergraduate science students exhibited lack of understanding about Nature of science and there is need to develop a sound understanding of NOS through appropriate curriculum and pedagogical intervention which are not kept under the scope of this study.

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