# Exploring Pre-service Science Teachers' Knowledge and Understanding of the Nature of Science

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**Abstract**

*The present research is to explore pre-service science teachers' knowledge and understanding of the nature of science by survey method using questionnaire and interview. The sample of the study included 693 pre-service science teachers under the Acharya Nagarjuna University by using random sample with disproportionate stratified sampling. Five per cent of the participating pre-service science teachers were interviewed following their responses in the questionnaire. In order to test the hypothesis, based on pre-service teachers' knowledge and understanding levels, one sample t-test is used and results indicate lack of significant currently accepted knowledge and understanding of the nature of science. The study reveals patterns showing that the pre-service science teachers had inadequate and conflicting views on several aspects of the nature of science. The study mainly recommends explicit teaching of the nature of science, including aspects of history, philosophy and sociology of science.*

## Introduction

The teacher preparation programme in Andhra Pradesh mostly focuses on pedagogical knowledge and assumes that teachers have content knowledge from their bachelor's degree. There is a lack of evidence in explicitly addressing the nature of science aspects in teacher training courses, and even in primary, secondary and

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tertiary education of pre-service science teachers. Rapid covering of the syllabus in teacher training programmes does not contribute significantly to pre-service science teachers' understanding of the nature of science.

It was observed that implicit messages from the curriculum, and formal and informal learning experiences contribute to pre-service science teachers' knowledge and understanding of the nature of science. The implicit messages might be in line with the current conception of the nature of science or it might be the cause of alternative conception and or misconception of the nature of science. If pre-service science teachers have alternative conception or misconception about the nature of science, this acts as a filter, might interfere and even obstruct new knowledge formation. Therefore, pre-service science teachers' prior conception of the nature of science is highly influential in filtering learning experiences from the teacher training course. It is imperative to know pre-service science teachers' conception or alternative conception or misconception about the nature of science.

The Indian National Curriculum Framework of Science Teaching (National Council for Teacher Education, 2009) emphasises that understanding of the nature of science is a major goal in science education. The importance of establishing adequate understanding of the nature of science is evident from the assertions made by researchers who argue that the nature of science constitutes a core objective of science education throughout the world (Akerson, Buzzelli, and Donnelly, 2008; Dogan and Abd-El-Khalick, 2008; Khishfe, 2008; Schwartz and Lederman, 2008; Martin-Diaz, 2006; Bell and Lederman, 2002; Bell, Lederman, and Abd-El-Khalick, 2000; Lederman, 1999, 1992; Abd-El-Kahlick, Bell, and Lederman, 1998).

## The Conceptual and Theoretical Framework

The nature of science is a crucial component of scientific literacy. In the present study, the two sub-concepts — scientific knowledge and scientific inquiry — combine to form the concept 'nature of science'. The study results will be interpreted in terms of current scientific worldview mostly guided by post-positivist understanding of the nature of science.

Understanding the nature of science promotes understanding of content knowledge. This is the foundation for pedagogical content knowledge, which directs appropriate use of the subject during the teaching career. An understanding of the current worldviews of the nature of science in terms of nature, generation, development, progression and validation of scientific knowledge, and, especially scientific theories, laws and scientific inquiry, are an important knowledge base for

learning and teaching. Inadequate understanding of the current views on the nature of science might hinder pre-service science teachers' learning.

The lack of adequate understanding of the nature of science promote teachers as information delivering agents, may promote rote learning and memorisation of concepts rather than conceptual understanding. This in turn leads to disinterest, lack of motivation and superficial learning of science.

A mammoth amount of research has taken place in different countries. The research results of Hassan (2001), Abd-El-Khalick and Lederman (2000), Murcia and Schibici (1998), and Kumano (1998) show that pre-service teachers do not possess adequate understanding of the nature of science. Literature review indicates that there are fewer empirical studies conducted on the nature of science in the Indian context. Therefore, there is a dire need of research in pre-service science teachers' knowledge and understanding of the nature of science in the Indian context.

## The Reasearch Questions

- To what extent does pre-service science teachers' knowledge and understanding levels reflect currently accepted views on the nature of science with respect to scientific knowledge and scientific inquiry?
- What are the patterns of pre-service science teachers' knowledge and understanding of the nature of science?

## Objectives

- To assess the pre-service science teachers' knowledge and understanding level of the nature of science with respect to scientific knowledge and scientific inquiry.
- To identify the patterns of pre-service science teachers' knowledge and understanding of the nature of science.

## Hypothesis

To answer the first research questions the following null hypothesis is made:

Pre-service science teachers do not have a significant level of currently accepted knowledge and understanding of the nature of science in terms of scientific knowledge and scientific inquiry.

## Significance of the Present Study

The results of the study help pre-service science teachers become aware of their understanding and critically reflect on their conception, which is important for shaping personal approaches to learning. The knowledge of the nature of science contributes to holistic meaningful learning of the subject such as in-depth understanding of science concepts, logical connection between science concepts, and promotion of higher levels of scientific thought such as critical thinking, reasoning and problem solving. If science learning is meaningful to the pre-service science teachers, it enhances motivation, interest in science and

promotes learning. The results of the study are significantly used to predict the type of teaching that might prevail in future by the current pre-service science teachers. The results also inform both teacher trainers and curriculum developers with a comprehensive picture of the pre-service teachers' knowledge and understanding of the nature of science and towards developing appropriate learning experiences.

## Limitations of the Study

The results are generalised to the pre-service science teachers of Andhra Pradesh.

## Methodology

The study included quantitative paradigm of research with cross-sectional survey.

## Population and Sample

The pre-service science teachers, who participated in the study, were registered students of the Bachelor of Education under the Acharya Nagarjuna University in Andhra Pradesh. They had completed their three-year Bachelors' degree in science before joining colleges of education. Enrolment into teacher training colleges is also based on the qualifying marks obtained in Education Common Entrance Test (Ed.CET) of Andhra Pradesh State Council of Higher Education (APSCHE).

Twenty per cent of pre-service science teachers were selected randomly with disproportionate stratified sampling. Five per cent of the sample was used for follow-up interviews.

## Tools and Techniques

### The Nature of Science Questionnaire

The nature of science written instrument was used to collect data. The questionnaire statements were developed from pre-existing questionnaires after intensive study from the literature by adopting, adaptation and construction of statements to suit particular conditions existing for the present study. The questionnaire consists of two parts — A and B. Part A gives concrete information about pre-service science teachers.

Part B contains 46 structured, close-ended statements on various dimensions of the nature of science. The statements are further classified based on sub-scales: scientific knowledge and scientific inquiry.

The Likert-type rating scale is used on a four-point continuum to indicate the level of agreement with each statement contained in the instrument. The cognitive level and epistemological sophistication were taken into consideration while developing the questionnaire. The statements were carefully presented both in English and regional language (Telugu). Science education lecturers and language experts were consulted during the process of translation of the questionnaire from English to the regional language (Telugu).

A pilot study was conducted to correct statements having indistinctness, misconstructions or several elucidations. The suggestions from the pilot study and subsequent recommendations from experts were used to revise the questionnaire. The calculated Cronbach's alpha co-efficient value for the nature of science is 0.780.

## Nature of Science Interviews

Semi-structured interviews were used to interpret and validate the pre-service science teachers' responses in the questionnaire. In addition, interviews were used to identify the general ideas of groups, emerging themes and follow-up on contradictions (Rubin and Rubin, 1995). During the preparatory phase of the research, semi-structured questions were drafted and finalised. Semi-structured questions were framed on the aspects of scientific knowledge and scientific inquiry.

## Procedure of Data Collection

The pre-service science teachers were randomly selected and requested for their participation in the study. At first, the nature of science questionnaire was administered personally by the researcher and later the nature of science interviews were conducted. Both instruments were accompanied by a letter of request, explaining the purpose of the research, and indicating that they had the choice to withdraw at any time from the study and promised to keep their responses confidential.

Five per cent of the sample pre-service science teachers were included in the interviews. The pre-service science teachers provided their answered questionnaire and were requested to provide an explanation to certain identified key aspects of the questionnaire in follow-up interviews.

The researcher analysed the interview data by finding patterns of thoughts or representative ideas. The researcher translated interview data which was examined by a second independent science education lecturer.

## Analysis and Results

The nature of science questionnaire data was subjected to a descriptive analysis (frequency and percentage) and inferential statistical analysis (t-test). Out of the 800 questionnaires distributed, 693 were returned to give a response rate of 86.60 per cent.

**Table A1**
**One Sample t-Test of Pre-Service Teachers' Knowledge and Understanding of Nature of Science: Scientific Knowledge and Scientific Inquiry (n= 693)**

| Nature of Science | μ | M | SD | SE | MD | t-value | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | 115.00 | 109.54 | 20.38 | 0.77 | -5.46 | -141.52* | 692 | .00 |
| Sub-scale: Scientific knowledge | 70.00 | 67.19 | 13.10 | 0.50 | -2.81 | -134.98* | 692 | .00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sub-scale:Scientif-ic inquiry | 45.00 | 42.35 | 9.29 | 0.35 | -2.65 | -119.99* | 692 | .00 |

*Note. M= sample mean; SD= standard deviation; SE= standard error; MD= mean difference; df= degrees of freedom; μ = population mean*
**p<.05.*

The null hypothesis i.e., pre-service science teachers do not have significant level of currently accepted knowledge and understanding of the nature of science in terms of scientific knowledge and scienitific inquiry, which was tested by performing one sample t-test (see Table A1). The test analysis shows that t-value of –141.52 for the nature of science, –134.98 for the nature of scientific knowledge, and –119.99 for scientific inquiry. The t-values are significant at the given alpha value. This indicates that pre-service science teachers' sample mean is less than the population mean on the nature of science, scientific knowledge and scientific inquiry. Therefore, pre-service science teachers lack significant level of currently accepted knowledge and understanding of the nature of science in terms of sub-scales — scientific knowledge and scientific inquiry.

In order to identify the patterns of pre-service science teachers' knowledge and understanding of the nature of science both the nature of science questionnaire and interview data were analysed. The results indicated the following patterns:

### Sub-scale: Scientific Knowledge

- The pre-service science teachers have conflicting views on the assumptions and purpose of science, and tentative nature of scientific knowledge.
- The pre-service science teachers have inadequate understanding of several aspects. Pre-service science teachers did not recognise the revolutionary changes of scientific knowledge, especially in scientific theories, origin of scientific laws, tentative nature of scientific laws, differentiating roles between scientific theories and laws, and relationship between hypothesis, scientific theories and laws.
- The pre-service science teachers have adequate understanding of science limitations, durability of scientific knowledge within the paradigm nature and role of scientific theories, including cumulative growth of scientific theories and evolutionary change of scientific theory and factors influencing acceptance of competitive theories within the scientific community.

### Sub-scale: Scientific Inquiry

- The pre-service science teachers have conflicting views on factors influencing scientists' work and subjective versus objective observations.

- They have inadequate understanding of the sequence of steps used in scientific method, and the difference between observations and inferences.
- The pre-service science teachers have adequate understanding of the role of imagination and creativity in scientists' work, plurality of scientific method and different scientists' observations on the same scientific phenomena.

## Discussion

### Sub-Scale: Scientific Knowledge

The results of the present study indicate that pre-service science teachers have conflicting views on the tentative nature of scientific knowledge. A majority of pre-service science teachers agreed that scientific knowledge corresponds directly to reality, therefore, it is not a subject to change (Matkins, Bell, Irving, and McNall, 2002). At the same time, pre-service science teachers also agreed that scientific knowledge is a subject to change (Akerson, Buzzelli, and Donnelly, 2008 Martin-Diaz, 2006; Bell, Lederman, and Abd-El-Khalick, 2000; Abd-El-Khalick and Lederman, 2000; Lederman, 1999).

Interview data indicate that a majority of pre-service science teachers acknowledge that scientific knowledge is tentative. Although interview data showed some changes in pre-service science teachers' understanding of the tentative nature of scientific knowledge, it is assumed that the questionnaire might contribute to the insights of the tentative nature of scientific knowledge. They expressed the view that the main reasons for the tentativeness of scientific knowledge are technological improvements. The results of the present study indicate the pre-service science teachers' contradictory views on the aspect of scientific theory change. They agreed that scientific theories will not change as they are built on accurate experiments. On the other hand, they also believe that scientific theories will change and this is due to scientists' reinterpretation or reconceptualisation of the existing observations (Abd-El-Khalick, 2005; Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002). The research results indicate that pre-service science teachers believe that theories change mainly due to new evidence and improvement in technology such as instruments (Liu and Lederman, 2007). Most pre-service teachers recognise only the evolutionary way of theory change.

Pre-service science teachers should recognise the tentativeness of scientific knowledge. This tentativeness is due to the interaction of many factors such as changes in research programmes, improvement of methods or methodological principles, changes in conceptualisation or reconceptualisation of existing concepts, changes in socio-cultural settings, technological advancements, new insights of the problem, changes in logical thinking, creativity and imagination, innovation of ideas, change or modifications in

experimental procedures, new insights of data collection, reinterpretation and analysis of data and logical arguments, etc.

Pre-service science teachers should recognise the evolutionary and revolutionary nature of science. They should be aware that scientific knowledge is theory-laden, socially and culturally embedded with human inferences, imagination and creativity. Therefore, subjectivity is inherent in scientific knowledge construction. The fact that pre-service science teachers should recognise the tentativeness of scientific knowledge does not mean uncertainty but is the characteristic of science's self-correcting aspect.

Pre-service science teachers' belief that scientific knowledge is fixed and cannot change have implications on their learning and teaching. They have an absolute positivist viewpoint that scientific knowledge is fixed and it will not change, belief in a rigid body of content for learning, and that at the heart of the learning process is putting more emphasis on regurgitation, rote learning and memorisation of the concepts rather than understanding. Most participants express that scientific knowledge is cumulative. The main reason behind that is that their curriculum components are based on highly factual knowledge and lack of components which stress the importance of reorganisation of how the scientific knowledge is derived.

The results of the present research indicate that pre-service teachers have conflicting views on assumptions and purpose of science. They agreed that science is a process which seeks the truth and also other contradictory ideas such as science seeks approximate answers to the questions of nature. They agreed that science attempts to prove the natural phenomena and also the alternative view that it attempts to explain and understand the natural phenomena.

The research results indicate that the pre-service science teachers are unaware of the revolutionary change of scientific knowledge. Those teachers who do not have current conception of revisionary changes are most likely to be confused when there is a change in scientific concepts. The pattern which emerged from the results indicated that pre-service science teachers had inadequate understanding of the tentative nature of scientific law. The pre-service science teachers did agree to scientific laws being proven, constituting absolute knowledge that will not change. They should recognise that scientific laws should be given high degree of probability. The pre-service science teachers' knowledge and understanding shows that their curriculum does not provide the learning experience that contributes to adequate understanding of the changing nature of scientific laws.

The pre-service science teachers have inadequate understanding of the degree of explanatory role of science theory and law. Most of them agree to scientific theories having less explanatory role than laws. Therefore,

they have inadequate understanding of the degree of explanatory power of scientific theories and laws. Pre-service science teachers should know that the degree of explanation, generalisation and predictive power is more in scientific theories than laws.

They also have inadequate understanding of the relationship between hypotheses, theory and law. They believe in hierarchical relationship that is hypothesis becomes a theory and theory becomes a law based on evidences (Dogan and Abd-El-Khalick, 2008; Liu and Lederman, 2007; McComas, 1998). In turn, such belief implies that laws have higher status than theories and hypotheses. This, in turn, implies that theories are less believable or valuable than laws (McComas 2003: 142; 1998: 54). The pre-service science teachers should recognise the fact that scientific theories and laws are distinct and provide a different kind of knowledge. If pre-service science teachers do not have knowledge of generation, development and status of scientific theories and laws, they cannot differentiate between various scientific theories and laws that are encountered every day in science learning. Moreover, they simply use terms, scientific thories and laws interchangeably. It is crucial to have an awareness of the difference and relationship between theories and laws and to recognise the predictive and explanatory function of theories and laws.

The results also demonstrated that pre-service science teachers have adequate understanding of science limitations and durability of scientific knowledge within the paradigm. If they have an adequate understanding of revisionary change (evolutionary and revolutionary) of scientific knowledge, they will consider flexible content for learning. This helps them to develop an open mind and indulge in continuous learning. The results of the present study indicate that pre-service science teachers have consistent views on the nature of scientific theories (Lederman, Abd-El-Khalick, Bell and Schwartz, 2002). They also have acceptable understanding of the role of scientific theories. They have sufficient understanding of cumulative growth and evolutionary development of scientific theories (Matkins, Bell, Irving and McNall, 2002). The results of the present research indicate that pre-service science teachers have adequate understanding that scientific theories and laws are different kinds of knowledge (Akerson, Buzzelli, and Donnelly, 2008).

### Sub-scale: Scientific Inquiry

The results also indicate that pre-service science teachers have conflicting views on factors influencing scientists' work. A majority of pre-service science teachers agreed that there are certain factors influencing scientists' work. They say personal, social, cultural and economic factors influence scientists' work.

In addition to the above, majority of pre-service science teachers believe that immediate surroundings of scientists can play a major role in research work. It is important to note here that some pre-service science teachers express the view that permission from authorities also plays an important role in scientists' work. They recognise that a degree of subjectivity is inherent in the construction of scientific knowledge in scientists' work (Akerson, Buzzelli, and Donnelly, 2008; Liu and Lederman, 2007). Although they are aware of subjectivity in scientists' work, at the same time, majority of them agreed that scientists' work will not be influenced by any factor. Therefore, they have conflicting understanding of the factors that influence scientists' work. The pre-service science teachers agreed that science is independent of culture.

Although several factors influence scientists' work, the scientific community tries to reduce subjectivity by peer review. Therefore, scientists work in a culture of scientific community as well as the culture of society. Pre-service science teachers should recognise the factors that influence scientific knowledge generation, development and validation. Such an understanding of the nature of scientific enterprise helps to accommodate different views, develop healthy scepticism towards scientific knowledge claims, believe in the construction of scientific knowledge and promote constructivist learning and teaching environment.

The pre-service science teachers had conflicting views on objectivity versus subjectivity in scientists' observations. Most pre-service science teachers' said that scientific observations were objective. They expressed that observations were objective because they were facts. Pre-service teachers did not have adequate understanding of scientific observations (Liang, et al., 2008; Schwartz and Lederman, 2008; Khishfe and Lederman, 2007).

Pre-service science teachers, when further probed about the objective nature of scientific observations, expressed conflicting views that observations of scientists were affected by their prior knowledge, as influenced by religious, moral and economic factors. Most of them initially articulated the presence of objectivity in scientists' observations, and later, the presence of subjectivity in their observations. Therefore, they have a conflicting understanding of scientific observations.

They should recognise that objective observations are not possible. The observations depend on previous knowledge, experiences and expectations. The observations are filtered through our perceptual system and interpreted in theoretical frameworks and assumptions. Scientists' observations are theory-laden and influenced by several factors such as theoretical arguments, disciplinary commitments, beliefs,

prior knowledge, training, experiences and expectations. All these are inter-related and influenced by social, religious, cultural, ethical, moral, political and economic factors.

Based on the above factors, scientists develop a personal understanding of the subject matter of investigation. These theoretical matters act like colour lenses through which observations are perceived and interpreted. Therefore, the observations are not objective but in fact, subjective. Scientists trying to achieve objectivity by checking procedures, by withstanding criticism of scientific community, etc., may limit theory-laden observations. It is not possible to completely eliminate subjectivity. Therefore, subjectivity is inherent in their work.

The results also show the pattern that pre-service science teachers used to express the view that scientists are supposed to follow a fixed sequence of steps in the scientific method. The basis of such inadequate understanding of the sequence of steps of scientific method might be from their science laboratory practices. Such laboratory experiences will reinforce step-by-step scientific method in order to get valid results. The textbooks and teachers might contribute to the above misconception. The pre-service teachers who had inadequate understanding of the scientific method containing fixed linear sequence of steps, has implication on science investigations or laboratory processes which are meant for theory confirmation. They will insist on following steps rigidly in science practicals and getting correct results.

Scientists do not follow a rigid order of activities. The pre-service science teachers should have adequate understanding of multiple methods used in science depending on the problem. It also helps them design and conduct experiments in an appropriate way. The results indicate that they also hold inadequate understanding of the difference between observations and inferences.

The results show that most pre-service science teachers believe in the role of imagination and creativity in scientists' work. Therefore, they have adequate understanding of the role of creativity and imagination in scientific investigations (Liu and Lederman, 2007). The main pattern revealed during the interview is that imagination and creativity play a major role in scientists' work in the planning and procedure stages only. Some felt that scientists use imagination in data analysis and evaluation stage. None of them expressed that scientists use imagination and creativity in data collection stage, data reporting stage, inventing new scientific ideas and invention of explanations (Abd-El-Khalick and Lederman, 2000). The pre-service science teachers who have adequate understanding of the role of imagination and creativity in science investigation will think critically and creatively in carrying out scientific investigations. Imagination and

creativity are essential for scientific progress.

Pre-service science teachers agree that scientists use different scientific methods depending on the problem they are investigating (Lederman, Abd-El-Khalick, Bell and Schwartz, 2002). The pre-service science teachers should be aware that science uses different methods based on problems of investigation, theoretical knowledge, instruments and materials available at that time. Such an understanding helps them use different scientific methods to solve diverse problems in their learning.

The results indicate that majority of pre-service science teachers agree that different scientists' observations on the same scientific phenomena are different. The above research results are in agreement with results of Schwartz and Lederman (2008); and Khishfe and Lederman (2007). Different scientists observing the same phenomenon or object will make different observational statements depending on their knowledge, experiences, expectations, theoretical frameworks and assumptions. Therefore, science theories precede observations.

## Conclusion

Pre-service science teachers lack significant level of currently accepted knowledge and understanding of the nature of science in terms of scientific knowledge and scientific inquiry. The results of the study also show that they have conflicting and inadequate understanding of many aspects of the nature of science.

The main reason for conflicting and inadequate understanding might be due to their formal and informal learning experiences and lack of explicit training in the nature of science. The implicit messages might contribute to the alternative conceptions of the nature of science. A close examination of teacher training courses show voluminous syllabuses and records of work to be covered within a short duration. The syllabus of the Bachelor's degree and teacher training courses are devoid of the nature of science concept. Textbooks and science laboratory experiences also contribute to alternative conceptions.

As pointed out by McComas (2003), lack of specificity of the elements that constitute the nature of science leads to the lack of inclusion of the nature of science components in the syllabus. Although the national curriculum framework of science teaching considers understanding of the nature of science as a primary goal of science education, it is not explicitly taught.

## Suggestions and Recommendations

Pre-service science teachers' curriculum needs to be reviewed and should include history, philosophy and sociology of science. The curriculum should include materials, topics, learning experiences, teaching

approaches, teaching methods and techniques that promote nature of science aspects in current post-positivist aspects. They are supposed to provide opportunities to pre-service science teachers to reflect on their concepts. Teacher educators are supposed to be aware of pre-service science teachers' misconception and deliberate attempt should be made to challenge and change their ideas. Teacher educators are supposed to participate in extensive in-service workshops on the nature of science in order to improve their understanding.

## Further Research

Further research includes repetition of the present research to establish the validity of the findings with a wide variety of research instruments. Comparative studies between pre-service, in-service science teachers and Bachelor of Science students are necessary. Research is required on curriculum components explicit and contextual teaching approaches of the nature of science.

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