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THESIS

ENHANCING BHUTANESE STUDENTS' VIEWS OF NATURE OF SCIENCE IN MATTER AND ITS COMPOSITION AND GAS LAWS THROUGH EXPLICIT AND REFLECTIVE APPROACH

PABI MAYA DAS

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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This study aimed to enhance Bhutanese ninth grade students' views of nature of science (NOS) through explicit and reflective approach. This study was divided into two phases. In first phase, cross-sectional survey aimed to explore Bhutanese ninth grade students' views of NOS. Stratified random sampling technique was used to generate the representative of the population. The adapted version of Students Understanding of Science and Scientific Inquiry (SUSSI) was used as a research tool. A total of 389 students from middle secondary and higher secondary schools from eastern, western, southern and central regions of Bhutan took part in this study. The results indicated that the majority of students held inadequate views of NOS in all aspects. Interestingly, none of the students held informed in scientific laws and scientific theories. In social and cultural embeddedness the majority of the students held naïve views.

The second phase of the study aimed to enhance students' views NOS through explicit and reflective approach. Seven aspects of NOS were integrated in chemistry content in Matter and Its Composition and Gas laws for a time span six weeks in one ninth grade class that comprised 18 students. A qualitative research approach was used as a research methodology. The same questionnaire in the first phase, semi-structured interviews, classroom observations, students' journals and assignments were used as data sources. Data were analyzed through inductive processes, to search and come up with patterns and themes. Students' views of NOS from pre-instruction and post-instruction questionnaire were categorized into naïve, transitional and informed. The results indicated that students' views of NOS at the end of the intervention had developed. However, the development was not parallel in all the aspects. It was also seen that NOS specific pedagogical knowledge and subject knowledge play an important role in teachers' ability to enhance students' views of NOS. The study has an implication for the curriculum developers and teacher professional developers to explicitly emphasize NOS in science curriculum as NOS is one of the key components of the scientific literacy.

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Student's signature Thesis Advisor's signature

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LIST OF ABBREVIATIONS

AAAS	American Association for the Advancement of Science
DCRD	Department of Curriculum Research and Development
ed.	editor
et al	Et alii
GNH	Gross National Happiness
GDP	Gross National Product
No.	Number
i.e	That is
NRC	National Research Council
NOS	Nature of Science
PPD	Policy Planning Division

CHAPTER I

INTRODUCTION

Overview of the Chapter

This chapter is an introductory chapter that provides background of the study, statement of problem, objectives, and research questions, scope of study and definition of the terms.

Background of the Study

Bhutan is nestled in the foothills of the Himalayas with rich culture and traditions. It was perhaps isolated until the start of five year development plans in 1961. The fourth king Jigme Singay Wangchuck commenced the changes by balancing modernization with its ancient culture and traditions through establishment of philosophy of Gross National Happiness (GNH) as the guiding principle of development (Child, Tenzin, Johnson and Ramachandra, 2012). Science education began in Bhutan with the borrowed science curriculum from the neighboring giant India. In 1986, Bhutan launched new science curriculum for the first time for primary levels, particularly for grades 4, 5 and 6, which then swapped the traditional way of learning by memorization of scientific facts. The inquiry-based classroom learning thereby flourished over the teacher-centered learning. In the year 1999 and 2000, three distinctively separate science disciplines namely biology, chemistry and physics till grade 8 were integrated and were replaced by the one and only Integrated Science. The curriculum for the higher levels, from grades 9 and above was kept the same, a teacher centered learning by memorization of scientific facts and figures and conducting the practical science works separately in the laboratories to confirm the theory taught (Child *et al*., 2012). Many weaknesses of the old curriculum had led to revision of the old science curriculum in Bhutan.

Bhutan strongly believes on the wellbeing and happiness of the country citizen that is largely influenced by the harmonious coexistence of people and its natural environment. The development of new science curriculum is unique. It has been designed underpinning the principles of GNH as an approach to teaching science which enables students to absorb the essence of living in harmony with the society and the environment. It aims to develop students to think and act scientifically, understand the power of science to explain the natural world and to appreciate the effects of science in establishing harmony with the principles of GNH. The revised science curriculum has emphasized on the inquiry-based and constructivist approach to the learning of science. (Department of Curriculum Research and Development [DCRD], 2012)

Statement of the Problem

Scientific literacy has become a central goal of science education across the world (American Association for the Advancement of Science [AAAS], 1990; National Research Council [NRC], AAAS, 1990; National Research Council [NRC], 1996; DCRD, 2012; Ministry of Thailand Education, 2008; Ministry of New Zealand, 2012). Scientific literacy has been defined in several ways: According to NRC, (1996: 22) “scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity.” A common misconception among many people is that they think scientific literacy as simply getting the information about the new advances that occurs. Possessing an accurate view nature of science (NOS) can help a person to be scientifically literate person in numerous ways. Understanding NOS has been continuously emphasized in science education around the globe as it is key components of scientific literacy (Meichtry, 1993; Driver, Leach, Millar, and Scott 1996; AAAS, 1989; McComas and Olson, 1998; NRC, 1996). An individual with adequate views of NOS are considered to be scientifically literate who can understand the developmental nature of scientific inquiry enabling them to readily accept the newly formulated ideas of science without any argument (Duschl, 1990).

The term NOS is defined as “The epistemology and sociology of science of science, science a way of knowing, or values and beliefs inherent to scientific knowledge and its development” (Lederman, 1992). NOS instruction is aimed to help students and teachers develop ways of knowing things and its philosophy about the generation, validating scientific knowledge and the nature of resultant knowledge (Abd-El-Khalick, 2012).

Over the past years, many empirical studies had examined high schools and junior schools students’ views of NOS using various assessment tools. Unfortunately, many of these studies have consistently found that students have inadequate and inappropriate views of NOS (Lederman, 1992; Akerson, Abd-El- Khalick and Lederman, 2000; Ryan and Aikenhead, 1992; Dogan and Abd-El- Khalick, 2008). For instance, Meichtry (1993) found that students did not understand NOS well enough to appreciate the tentativeness nature of scientific knowledge. Kang, Scharman, and Noh (2005) found 6^{th}, 8^{th} and 10^{th} grade Korean students held absolutist/ empiricist views of NOS. Similarly, Rubba (1977) concluded that secondary students believed that scientific research would lead to absolute truth. Mackay (1971) concluded that students did not have sufficient knowledge on the role of creativity of science, distinction among hypothesis, laws and theories, and the function of scientific models. Bell, Crawford and Lederman (2003) found that students held misconception. They believed that with more evidences scientific theories can eventually be proven, scientific laws are absolute and the students showed strong belief in a single scientific method.

The main purposes of teaching NOS is to motivate and encourage students to deeply understand the nature and relationship between science and technology, to encourage students to investigate the history and origin of scientific facts and ideas, to enable them to appreciate the roles and responsibilities of science and technology in improving personal lives and the society (Hand, Prain, Lawrence and Yore, 1999). Understanding of NOS enhances students’ ability to critically emulate scientific inventions and their benefits and also help themselves in the debates surrounding both current and the future scientific issues. Furthermore, an understanding of NOS enhances the learning of science content, understanding of science and develops positive and scientific attitudes towards learning science (McComas, Clough, and Almazroa, 1998; Clough and Olson, 2012). Therefore, helping students to develop adequate understanding of NOS has become a central goal of science instruction in many countries (AAAS, 1990, 1993; NRC, 1996; New Zealand, 2011; IPST, 2008).

Many science educators and researchers argue that explicit approach of addressing NOS increases the effectiveness of understanding of NOS as compared to implicit approach (Abd-El-Khalick and Lederman, 2000; Abd-El-Khalick, 2001; Khishfe and Abd-El-Khalick, 2002; Khishfe, 2008; Schwartz, Lederman and Crawford, 2004; Bell, Matkins and Gansneder, 2011; Lederman, Abd-El-Khalick, 2002; Yacoubian and Boujaoude, 2010). In an explicit approach the aspects of NOS are mentioned explicitly in the objectives of the lesson and the students are provided an opportunity to discuss and reflect the aspects of NOS. In an implicit approach, there is assumption that the students will learn NOS automatically when students are engaged in inquiry activities while learning science.

Like many other countries, Bhutan's science education is in the nascent state. The revision of science curriculum is the stepping stone to improve the quality of science education in Bhutan. It aims towards the development of scientifically literate citizen to meet the changing needs for Bhutanese society keeping in mind the Gross National Happiness (GNH) principles as the nation's aspiration (DCRD, 2012). Although, Bhutan does not have separate strands that explicitly focuses on enhancing students' understanding of NOS like in many countries, how science works, investigation and experiments are merged together as working scientifically whereby Bhutanese students are expected to understand NOS automatically when science lessons are being delivered through inquiry oriented approach. (DCRD, 2012).

In this 21st century, science and technology are rapidly advancing and science literacy is becoming more and more important to support and ensure quality life for the whole world. And Bhutan is not an exception. To educate Bhutanese students in scientific inquiry, scientific world views and the scientific enterprise are crucial aspects. Lack of understanding of science and technology will lead to more and more misconception by Bhutanese students who become plugged into the world through electronic media. Social media like television, internet, comics, newspaper, cartoons, science fiction movies, etc., can lead to misunderstanding and thereby misconceptions for many students. In addition, students learning science only to accumulate mere facts will more likely de-motivate the learning of science in the long run. Loving (1991: 824) states that “Students need to be given an accurate picture of what science is and is not, of its relation to technology and of each to society, of good versus poor science, of what it took to get where we are today, and of the continuous struggle in all disciplines to come up with better explanations about natural phenomena.” Moreover, the ability to differentiate good science from pseudoscience depends on how much students understand the nature of science, as the students with naïve views of NOS could be easily fooled by the widely spreading pseudoscience (Good, 2012). Since, NOS is not explicitly emphasized in the Science Curriculum Framework in Bhutanese Education, I as a science teacher as well as a researcher realize that NOS is fundamental for a quality science curriculum. A quality education means students reaching scientific literacy to be able to more fully link to the global prospective.

Science educators (e.g., Bell, Matkins and Gansneder, 2011) suggested that a contextualized approach is better for promoting long-term retention of NOS concepts and few empirical studies have been conducted integrating NOS in chemistry content. However, no research has been conducted in Bhutan to explore students’ and teachers’ views on NOS and in the international perspective integrating NOS in Matter and Its Composition and Gas Laws in the normal classroom teaching across the globe. This study focus to integrate seven aspects of NOS: tentativeness nature of scientific knowledge; the empirical nature of scientific knowledge; observation and inference; creativity and imagination; scientific theories and laws; scientific methods and social and cultural embeddedness in Matter and Its Composition and Gas Laws in grade nine chemistry course. In light of this, it is thought appropriate to fill up the gap through this study and find out the students’ views of NOS at the present situation and the appropriateness of the topic of Matter and Its Composition and Gas Laws as a pathway to enhance students’ views of NOS. The inferences drawn from this study would support science teachers, policymakers, teacher educators and curriculum developers to see the importance of explicitly emphasizing NOS while teaching science lessons. In addition, it is hoped that the results will further strengthen Bhutanese students' views of NOS and lead to further research on NOS.

Objectives

This study has two objectives. The first objective is to explore Bhutanese ninth grade students' views of NOS and the second objective is to examine how explicit and reflective approach enhances Bhutanese students' views of NOS.
To fulfill the objectives, this study was guided by the following research questions:

1. What are the views of NOS among Bhutanese ninth grade students?
2. How does explicit and reflective approach influence ninth grade Bhutanese students' views of NOS?

Scope of the Study

This study is divided into two phases.

Phase 1

Phase 1 of the study is a cross sectional survey research conducted in the month of October to November 2013 with ninth grade Bhutanese students from 14 schools comprising of 389 students from the middle secondary school and higher secondary schools of Bhutan. This phase is aimed to explore ninth grade students' views of NOS and is a baseline of the phase 2. Stratified simple random sampling method was used as to find out the sample size.

Phase 2

Phase 2 is a case study conducted in beginning of the school academic year, 2014 for duration of six weeks. This phase is an intervention to enhance ninth grade Bhutanese students understanding based on the results of phase 1 through integrating NOS in chemistry content. One higher secondary school from the western region of Bhutan was selected for the intervention through purposive sampling method

Definition of the Terms

Nature of Science (NOS)

Learning of NOS is blend with working scientifically in strand 1 in the Science Curriculum Framework of Bhutan in which some of the aspects of NOS is addressed in the learning outcome. The core aspects of NOS focused in this study are: tentativeness nature of scientific knowledge; the empirical nature of scientific knowledge; observation and inference; creativity and imagination; scientific theories and laws; scientific methods and social and cultural embeddedness.

Explicit and reflective approach

Explicit and reflective approach is an approach which intentionally draws learners' attention through the discussion and guided reflection of aspects of NOS along with the engagement in the inquiry activities. The aspect of NOS is paid attention and planned through objectives, instructions and in the assessments providing students with experiences in scientific inquiry at the start, followed by explicit discussions and reflections about the nature of science.

Summary

Scientific literacy is the central goal of science education around the world. Similarly, scientific literacy is one of the main goals of science education in Bhutan as per the new science curriculum framework. Although, developing appropriate views of NOS are major concerns worldwide, many research studies have found that both students and teacher do not have adequate understanding of NOS. With an aim to enhance Bhutanese students' views of NOS, an explicit and reflective approach was used in chemistry content in Matter and Its Composition and Gas Laws which in turn contributes to be scientifically literate citizens.

CHAPTER II

LITERATURE REVIEW

Overview of Chapter

This chapter provides information on theoretical framework underpinning this study. It provides information about NOS, aspects of NOS, comparison of different science educators, science education and nature of science in Bhutan, importance of students' understanding and learning of NOS, teachers' teaching practice in NOS, and assessment in NOS.

The Nature of Science (NOS)

There are many debates going on among science philosophers, science historians, and science sociologists about the specific and precise definition of the NOS. There are many definitions of NOS that has been considered by many science educators. McComas and his colleagues (1998) focused on the merging of various aspects of social science such as how science works, how scientists work as the social group including the psychology of observation which requires careful observation and how society itself both directs and reacts to scientific endeavors. McComas and his colleagues (1998: 4) defined NOS as "a fertile hybrid arena which blends aspects of various social studies of science including the how science operates, sociology, and philosophy of science combined with research from the 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." Presently, Lederman's definition is widely recognized. It focuses on the knowledge of science including creativity, imaginative, subjectivity, empirical based and the importance on social and cultural values in the production of the scientific knowledge and he concludes NOS "As the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman, 1992).

Aspects of Nature of Science

There is an acceptable level of generalization concerning some aspects NOS, which are less controversial but the aspects on NOS that are emphasized may vary among science educators. Table 2.1 shows some of the variation in the aspects of NOS taken by different science educators.

Table 2.1 Comparison of aspects of NOS among different science educators

	Lederman *et al*., (2002)	**McComas (2004)**	**Liang *et al*. (2009)**
Aspects of NOS	Tentativeness of scientific knowledge	Scientific knowledge is tentative but durable	Tentativeness of scientific knowledge
	Subjectivity (theory-Laden)	Science has a high subjective	Subjective and objective in science
	Creativity and imagination	Science is a highly creative	Creativity and rationality
	Socially and culturally embeddedness	Science and technology impact each other	Socially and culturally embeddedness
	Distinction between scientific theories and laws	Laws and theories are related but distinct kinds of scientific knowledge	Scientific theories and laws
	Observation and inference		Observation and inference

Table 2.1 (Continued)

	Lederman *et al*., (2002)	**McComas (2004)**	**Liang *et al*., (2009)**
Aspects of NOS	Empirically based scientific knowledge	Science relies on empirical evidence Science and its method cannot answer all questions	

Source: Lederman *et al*. (2002); McComas, (2004), and Liang *et al*.(2008)

Although the aspects of NOS emphasized vary among different science educators, but there are some common aspects of NOS that are emphasized. Most of the aspects of NOS are similarly viewed by different science educators. McComas (2004) has emphasized nine aspects of NOS, Lederman *et al*. (2002) has emphasized seven aspects of NOS and Liang *et al*. (2009) emphasized on seven aspects of NOS. All of these authors have similar aspects, but use different terms to describe the concepts based on their beliefs. For instance, Lederman *et al*. (2002) uses 'scientific knowledge is theory laden' whereas Liang *et al.* (2009) uses 'subjectivity and objectivity in science'. For scientific method, Lederman *et al.* (2002) uses 'myth of scientific' where as Liang *et al.* (2009) uses scientific 'scientific method'. Although McComas (2004) has nine aspects of NOS, they overlap with one another. For instance, social influences on science and technology impact each. The historical, cultural, and social influence on science are kept as two different aspects but Lederman *et al.* (2002) and Liang *et al*. (2008) have merged together and made it as 'socially and culturally embeddedness.

Lederman (2007: 836) stated that "Regardless of various problems associated with reaching consensus on various aspects of NOS, and issues created by the tentativeness of the constructs itself, the NOS have been the object of systematic educational research for approximately 50 years." The aspects that are in level of generality and where no disagreement exists among historians, philosophers, science educators and have been emphasized on many reforms and empirical studies (e.g., AAAS, 1990, 1993; Abd-El-Khalick and Lederman, 2000; Liang *et al*., 2006) are scientific knowledge is tentative; empirically based; subjective (theory-laden); partly the product of human inference, imagination, and creativity; and socially and culturally embedded, distinction between observation and inference and the function of and relationships between scientific theories and laws.

The Empirical Nature of Scientific Knowledge

Science is not fully based on observations of the natural world as its findings at the end should be settled by referring to observations of phenomena (AAAS, 1990). Any scientific explanation depends on empirical evidence or experimental data. Scientists depend on empirical evidence in the form of quantitative and qualitative data to produce scientific knowledge. Nevertheless, most of the time scientists do not get a direct access to most of the natural phenomena e.g., to study atoms, black holes, galaxy, etc., scientists use their senses and or sophisticated instrumentation in order to draw realistic and believable conclusion (Lederman *et al*., 2002).

Tentativeness Nature of Scientific Knowledge

Scientific knowledge is reliable and durable but is not absolute to be proven in final sense. Scientific claims, theories, laws are subject to change over a period of time when more empirical data emerge, when scientists reinterpret old evidence with advance in thinking or advancement in the technology. No matter how well the theory explains the set of observation; changes in scientific knowledge or theories are unavoidable. Therefore, scientific knowledge can be modified, disproved or approved depending upon the availability of the new evidence, reinterpretation of the existing data and due to advancement in the technology. “The history of science could be both evolutionary and revolutionary change” (Liang *et al*., 2006: 9).

Observation and Inference

Science is based on observation and inference. Students of science should be able to set clear difference between observation and inference. Observations are simple statements that describe the natural phenomena which are directly accessible to the senses and to which observers can make decision that is appropriate. For instance, objects released above ground level tend to fall to the ground. On contrary, inferences are statements about phenomena that are not directly accessible to the senses. For example the statement, "objects tend to fall to the ground because of gravity." The observation is that things fall to the ground, while the notion of gravity is inferential in the sense that it can be measured only through its manifestations such as the perturbations in predicted planetary orbits due to interplanetary attractions (Lederman *et al*., 2002).

Creativity and Imagination

Scientific knowledge does not just emerge only from experiment and data analysis. Science is a human endeavor relying on the human qualities, like reasoning, skills, insight and creativity. The development of scientific knowledge involves making careful observations of nature and natural phenomena. Science opposing to common belief is not a lifeless, entirely rational, and activities in generating scientific knowledge; it involves human imagination and creativity. Scientists use creativity and imagination in all the steps involved in investigation (Lederman *et al.,* 2002).

Social and Cultural Embeddedness of Scientific Knowledge

Science is a human endeavor and is influenced by historical, cultural and social events. Scientific knowledge has to be digested ultimately by humans who are in turn abided by historical, cultural and social laws, undoubtedly science facts have to be compatible/palatable with these artifacts. The values and expectations of culture determined what and how science is conducted, interpreted, and accepted. Therefore, science and society are interwoven and inseparable to the extent that some scientific studies are even barred by social norms.

Scientific Theories and Laws

Scientific theories are well established sets of concepts that can explain observations based on more than one investigation. More importantly, theories play great roles in generating research problems and enquiries. Therefore, theories are based on probable assumptions which make theories not directly testable. Scientific theories offer an explanation of why a particular phenomenon occurs. For example, kinetic molecular theory explains the relationship expresses by Boyle's law in terms of collision of gas molecules with the walls of the container with increase in pressure. On the other hand, laws describe the generalization relationship or patterns between observable phenomena. It describes what happens to the natural world and are often expressed in mathematical expression. For example, Boyle's law describes the relationship between the pressure and volume of a gas at a constant temperature. It states that at constant temperature, the pressure of a gas is inversely proportional to its volume. Theories do not become laws even with additional evidence; they explain laws. Therefore, theories differ from laws as they are inferred explanations for observable phenomena. Both scientific theories and scientific laws are subject to change (Lederman *et al.*, 2002).

Scientific Methods

Different types of scientific knowledge are investigated through various kinds of scientific methods. There is no single step by step universal scientific method to do science. Scientists use a variety of methods and approaches to generate scientific knowledge, including observing, inferring, and experimenting, speculating, library investigation, hypothesizing, and creativity and constructing theories and explanation (Lederman *et al*.,2002).

Science is not just study of mere facts and figures. Science is a body of knowledge, and way of knowing where body knowledge refers to products of science; methods refer to various ways to obtain scientific knowledge and a way of knowing deals with the science values and the characteristics of scientific knowledge. Science is based on empirical evidence, tentativeness, creativity, imagination, and subjectivity. All these components of science go hand in hand and need to be given a place in the process of learning science. The present study is focused on the seven aspects of the nature of science, which are appropriate in the context of my study with ninth grade students of Bhutan. The aspects NOS that have been focused in this study are: scientific knowledge is tentative (subject) to change; empirically based; imagination and creativity; methods of scientific investigation; observation and inference and distinction between law and theory. Moreover, these aspects of NOS are appropriate for the secondary level students as they provide accurate views of scientific enterprise and have been emphasized in Benchmarks for science learning. (AAAS, 1993, 2009; New Zealand Science Curriculum Document, 2011; DRCD, 2011; Lederman *et al.*, 2002**)**

Science Education and Nature of Science in Bhutan

Bhutan, a small mountainous country located on the foothills of Himalayas between two giants, China in the north and India in the south, is now known for Gross National Happiness (GNH). With about 38,394 sq km of area, agriculture is the backbone of its economy, it contributes more than 33% of the Gross Domestic Product (GDP), and over 70% of Bhutanese depend on it for their livelihood. Of late, manufacturing industries, hydroelectric power projects and service industries are emerging and gaining their importance in the country. The national vision of Bhutan is "Bhutan aspires to be self-reliant, economically prosperous, environmentally healthy and sustainable, democratically sound and culturally vibrant, the citizens of which are creative, highly skilled and capable of responding to the emerging global challenges and contributing to equitable and sustainable socioeconomic development and well-being of their community and the nation" (Royal Educational Council [REC], 2012: 3).

Science Education began in Bhutan with the borrowed science curriculum from India. In the year 1986, Bhutan launched new science curriculum for the first time for primary levels, particularly for grades 4, 5 and 6, which then replaced the traditional way of learning by memorization of scientific facts. It thus, succeeded over the outdated rote-learning by its inquiry-based classroom learning. In the year 1999 and 2000, three distinctively separate science disciplines namely biology, chemistry and physics till grade 8 were integrated science in single science. However, science curriculum for classes 9 to 12 continued to be taught more with the same teacher-centered approach coupled with rote learning of the textual facts allowing less scope for classroom interaction and out of the box thinking. Further, it was found that science practical classes conducted in the laboratories were weakened due to lack of time, content coverage overload, lack of administrative and academic support, lack of teachers' practical knowledge and expertise, under qualified lab assistants, short supply of equipment and resources, and other reasons such as these. Furthermore, it was found that Bhutanese Education System has not been able to produce students with sufficient technical and scientific knowledge and skills (Child *et al.*, 2012).

With many aforementioned challenges, now Bhutan has developed a new Science Curriculum Framework underpinned by Gross National Happiness principle (GNH). The revised Science Curriculum Framework has emphasizes on the primacy of inquiry-based, constructivist and investigative approach to the learning of science. It aims to develop the scientific knowledge, skills, and dispositions, to enable students to think and act scientifically, understand the power of science to explain the natural world and to appreciate the effects of science in establishing harmony with the principles of GNH. GNH principles are governed by four pillars: culture, environment, socio-economic development and the good Governance, supported by the 9 domains such as ecology, psychological well-being, time use, education, health, community vitality, cultural diversity, standard of living and a good environment. The Science Curriculum Framework has organized learning science into four strands: Strand 1: working scientifically; Strand 2: Life processes; Strand 3: Materials and their properties; Strand 4: Physical process. Keeping in mind the GNH principle, the following are the goals of science education (DCRD, 2012: 12-14).

1. To enable learners to acquire knowledge and understanding of the natural sciences at a level appropriate to their developmental stage.

2. To develop and apply the skills of inquiry, investigation, problem-solving and logical reasoning.

3. To be 'scientifically literate' and able to participate in critical and informed debate on the key questions and issues that may affect their own lives, their community and their country.

4. To prepare learners for higher studies in science and technology.

5. To equip learners with the knowledge, understanding and skills in science to allow them to make a smooth transition into jobs in the workplace that require an understanding of science.

6. To instill in learners a love and care for the natural environment and to develop the necessary understanding to be able to live harmoniously with nature and realize the goal of sustainable development.

7. To equip learners with knowledge of local as well as global environmental and ecological problems, their consequences and solutions.

8. To develop a sense of health and well-being and how to live a healthy life.

9. For learners to understand that there are some questions science can address but there are others, for example questions of religion, that it cannot answer.

10. To inculcate in learners a love for learning science and carry it on further into their lives.

As mentioned earlier, Bhutan has as of now just completed the development of its Science Curriculum Framework which has entailed a large scale research and study as to what curriculum would best benefit the Bhutanese people. The implementation of this curriculum is being carried out grade wise. When the study was conducted, implementation of new science curriculum had begun in grades four, five, six, and seven. Since implementation of new science curriculum was being carried out in phases, at the time of this study the grade nine students were still learning old syllabus which basically focused on the traditional instructional methods.

In Bhutan NOS is not explicitly emphasized but it is merged as working scientifically. At the end of each key stage students are expected to learn how science works from their involvement in designing investigations and experiments; gathering and communicating evidence, planning, concluding and evaluating. Students are to understand the power and limitation of science as it addresses the social ethical and environmental issues in relation to making judgments and decisions. Students need to know how scientists work together as team to develop new scientific knowledge, how this new scientific knowledge may lead to disagreement in the social cultural and religious contexts. In addition, learning science should help students to discover a wider range of scientific ideas, and apply scientific knowledge in the new context. While carrying out the scientific investigation students also need to select and plan their investigation or inquiry using a wide range of techniques to compare, contrast, synthesize and critique the different sources of information and draw conclusions. Some of the aspects of NOS extracted from the learning outcomes expected of by the end of the grade nine to grade ten are mentioned in Table 2.2.

Table 2.2 Aspects of NOS present in science curriculum as learning outcome in key Stage 4 (grade 9 to 10)

Aspects of NOS	**Learning Outcome**
Observation and inference	- Use observations, measurements and their scientific knowledge and understanding to draw conclusions.
Scientific method	- Consider the extent to which the evidence collected is sufficient to answer the questions devised and to support any conclusions or interpretations made. - Make sufficient observations and measurements to reduce error and obtain reliable evidence. Decide whether to use evidence from first-hand experience or secondary sources, such as scientific articles, and judge the validity and reliability of these sources.
Tentativeness of scientific knowledge	- Describe how science differentiates itself from other ways of knowing that scientific explanations must meet certain criteria, and that all scientific knowledge is subject to change as new evidence becomes available.
Distinction between Scientific Theories and Laws	- Use theories and models to develop scientific explanations. Recognizes that theories and models can help to explain some ideas in science but that they also have their limitations.
Social and cultural embeddedness	- Give examples of the ways in which scientific work may be affected by the social, historical and cultural contexts in which it takes place, and how these contexts may affect whether theories and ideas are accepted.

Table 2.2 (Continued)

Aspects of NOS	Learning Outcomes
Empirical nature of scientific knowledge	- Decide whether to use evidence from first-hand experience or secondary sources, such as scientific articles, and judge the validity and reliability of these sources. - Identify anomalous data giving reasons for rejecting or accepting them using their scientific understanding, and consider the reliability of data in terms of the uncertainty of measurements and observations. - Consider key factors that need to be taken into account when collecting evidence, and how evidence can be collected in contexts (for example in fieldwork) in which variables may not easily be controlled

Source: (DRCD, 2012: 28)

One of the goals of science education in Bhutan is to produce scientifically literate citizens, who can apply skills of inquiry, investigation, problem solving and logical reasoning and thereby understand the natural world through inquiry oriented and constructivism teaching approach underpinned by GNH principles. However, many empirical studies have shown that students do not automatically learn NOS including the nature and process of science. It is understood only through doing, hands-on science, or authentic inquiry-oriented investigations. Many researchers (e.g., Abd-El-Khalick, and Lederman, 2000; Abd-El-Khalick, 2001; Khishfe and Abd-El-Khalick, 2002) argues that it may not be effective when the lesson are taught through inquiry approach alone. Furthermore, Lederman (2007) pointed out that many individuals often conflate NOS with processes or scientific inquiry although they overlap and intersect, but it is important to distinguish between these two.

Importance of Students' Understanding and Learning of NOS

The most important reason for emphasizing NOS in science education by the science educators is that NOS is one of the key components of scientific literacy (Meichtry, 1993; Driver *et al*., 1996; AAAS, 1998; NRC, 1996). Lederman (1992: 332) stated that "Concerns for the development of adequate understanding of NOS have worn many hats through the years." Further, he pointed out that although there are differences in science curricula among the countries, states, schools districts and the individual schools and these differences are unavoidable. However, the common objectives and learning outcome of science instruction is to develop an adequate understanding of NOS. Bell (2008) pointed that a basic reason to teach NOS is to help students to develop accurate views of what science is, how science is different from other disciplines, what science can answer and what are the strengths and limitation of science. Many empirical studies have shown that understanding of NOS has numerous benefits to the students. For instance, understanding of scientific knowledge in decision making involves understanding of the process through which scientific knowledge is produced, and not only the end product of scientific knowledge (Bell, 2008). Understanding of NOS can enhance students' understanding of science and interest in science (McCOmas, Cough, and Almazroa, 2000). Further, Driver *et al*. (1996) argues that understanding of NOS is the key component of scientific literacy and they emphasized five important reasons to teach NOS:

1. Utilitarian: to make sense of the science and manage the technological objects and processes they encounter in everyday life.

2. Democratic: is necessary for the people to make sense of socio scientific issues and participate in the decision-making process.

3. Cultural: to appreciate science as a major element of contemporary culture.

4. Moral: to help develop awareness of the nature of science, and in particular the norms of the scientific community, embodying moral commitments which are of general value.

5. Science learning: to support successful learning of science content

As mentioned earlier, many countries around the globe have given the top most priority to enhance students' and teachers' understanding of NOS in the science education for a century and more (AAAS, 1990; NRC, 1996). However, despite of the major efforts taken to improve, research has shown that students and teachers often hold misconception about nature of science (Lederman, 2007). McComas (2000) pointed that "misconception about science are most likely due to lack of philosophy of science content in teacher education programs and the failure of such programs provide real science research experience for pre-service teachers while another source of the problems may be the generally shallow treatment of the nature of science in the textbooks to which teachers might turn for guidance." Some of the myth of science held by students and teachers according to McComas (2000: 54-68) are addressed below:

1. Hypotheses become theories that in turn become laws.
2. Scientific laws and other such ideas are absolute.
3. Hypothesis is an educated guess.
4. General and universal scientific method exists.
5. Evidence accumulated carefully will result in sure knowledge.
6. Science and its methods provide absolute proof.
7. Science is procedural more than creative.
8. Science and its methods can answer all questions.
9. Scientists are particularly objective.
10. Experiments are the principal route to scientific knowledge.
11. Scientific conclusions are reviewed for accuracy.
12. Acceptance of new scientific knowledge is straightforward.
13. Science models representative reality.

14. Science and technology are identical.
15. Science is a solitary pursuit.

Over the past years many empirical studies have examined high and junior schools students' views of NOS using various assessment tools, unfortunately, many of these studies has consistently found that students have inadequate and inappropriate views of NOS (Lederman, 1992; Akerson, Abd-El- Khalick and Lederman, 2000; Ryan and Aikenhead, 1992; Dogan and Abd-El- Khalick, 2008). For instance, Meirchtry (1993) found that students did not understand NOS well enough to appreciate the tentative nature of scientific knowledge. Rubba (1977) concluded that secondary students believed that scientific research would lead to absolute truth. Similarly, Kang, Scharman, and Noh (2005) reported that Korean 6^{th}, 8^{th} and 10^{th} grade students held absolutist/empiricist views of NOS. Bell *et al.*, (2003) in eight weeks science apprenticeship programs on ten volunteers groups of high ability students from grade 10 and 11 found that students held misconception and they believed that with more evidence scientific theories can eventually be proven, and scientific laws are absolute and the students showed strong belief in a single scientific method.

Mackay (1971) concluded that the students did not have sufficient knowledge on the role of creativity of science; distinguishing hypothesis scientific laws and scientific theories, and the functions of scientific models. Khishfe (2008) in her study with 62 sixth graders found that students were not able to differentiate between observation and inference; students did not have an adequate understanding about the role of empirical studies in generating scientific knowledge and students noted that scientist do not use creativity and imagination. Abd-El-Khalick and Bonjaoude (2010) in their study found that the majority of the students held restricted views of NOS and defined science as an academic subject and also that study of science for future careers. Haidar and Balfakih (1999) in their studies with Emirte high school science students found that the majority of the students had uninformed views in scientific method. Sangsa-ard, Thathong and Chapoo (2013) in their study with 71 grade nine students found that students did not reveal that social and cultural values influence science but stated that scientific enterprise is unrelated to public. They were with the views that scientific theories are less stable than the scientific laws, a common misconception indicated in many studies. Driver *et al*. (1996: 33) pointed that "if students do not understand scientific laws and theories are conjectural and cannot see where an explanation comes from, they may either adopt a passive (rote learning style which is inefficient at best, or decide that science is not for them" They further pointed out that many students think that the scientific ideas, laws and theories come from the observational data.

Finally, McComas (2000: 68) concluded "We must rethink the goals for science instruction. Both students and those who teach science must focus on the NOS itself rather than just its facts and principles. School science must give students an opportunity to experience science and its processes, free of legends misconceptions and idealizations inherent in the myths about the nature of scientific enterprise.

Teaching NOS

A teacher plays crucial role in enhancing students' understanding of NOS. As of now professional development program related to enhancing understanding of NOS and teaching NOS for the teacher has been emphasized and given the priority. Many measures have been taken to improve teachers' understanding of NOS. However, various empirical studies have shown most science teachers, both pre-service and in-service, hold inadequate conception of the NOS (Lederman, 1992). Teachers are also unable to transform the NOS into practice due to lack of NOS understandings, lack of attention, awareness about the roles of NOS, resources, experiences, time to plan (Abd-El-Khalick, Bell and Lederman, 1998; Lederman *et al*., 2001). Akerson and Volrich (2006) argue that teachers' attentions and motivations serve as a key factor to teaching the NOS. Teaching NOS can depend on an individual teacher, but a teacher is expected to use the most effective and appropriate approaches to promote students' understanding of NOS in their instruction. The following are the instructional approaches used in teaching NOS:

1. Historical approach
2. Implicit Approach
3. Explicit-Reflective Approach

1. Historical Approach

There has been long tradition where scientists have supported the cultural, educational, personal and scientific benefits of infusing the history and philosophy of science into science curriculum, which in modern times is termed as NOS (Matthews, 2012). Historical approach has been one of the approaches used for developing students' and teachers' conception of NOS and has been quite popular in the past (Kipnis, 2000). Historical approach assumes that students will recognize the aspects of NOS embedded in the historical episodes. Clough, Herman and Smith, (2010) conducted on 134 post-secondary majors biology students. The study showed that historical short stories had positive impacts on students' understanding of NOS where by the students showed in the interest in science careers and in learning science content. "Historical reading combined with investigation experimentation especially of a historical nature appears to be a promising way for students to learn the basics of the scientific method and understand some other issues of the nature of science even subject is presented unobtrusively" (Kipnis, 2000: 192).

Monk and Osborne (1996) further point out that inclusion of history of science in science curriculum provides ways to comfort and recognize that others have thought in a similar manner and to hold such thoughts is not to be guilty of mere stupidity as some of the highly respected and intelligent men in the past had also thought in very similar ways. The past, and current thinking offers an improvement over past trend of thoughts, the present thought therefore becomes a new idea, which is more valuable in its scope, detail, utility, and predictions where the past history. Abd- El-Khalick and Lederman (2000) argues that history of science courses do not necessarily enhance students' and teachers' understanding of NOS as it is difficult for the teachers and students to transfer and apply the knowledge and understanding that they gain from one context to another similar context.

2. Implicit Approach

The implicit approach emphasizes on doing science, with an assumption that student learn NOS through scientific investigations and doing science, itself will help students develop more accurate understandings of the nature of scientific inquiry and knowledge (Bell, Matkins, Gansneder, 2011; Bell, 2001). For instance, when students are involved in inquiry oriented activities and are using science process skills, they are expected to develop sufficient understanding of the NOS (Schwartz *et al.*, 2004). However, research has consistently shown that implicit approach is inefficient in enhancing students' and teachers' understanding of NOS. For example, Moss *et al.* (1998) in his yearlong investigation on environmental science class with 11th and 12th grade who were engaged in inquiry-oriented projects involving students in partnership with scientists found that these students did not show significant changes in their views of science.

Similarly, Bell *et al.* (2003) in their study with ten volunteers groups of high ability students from grade 10 and 11 in eight week's science apprenticeship program did not show many changes in their understanding of NOS and scientific inquiry. Instead students had misconceptions like: scientific theories are proven with more evidence, scientific laws are absolute and had strong belief in a single scientific method were noted after the apprenticeships program.

Khishfe and Abd-El-Khalick (2002) in their study with 62 sixth graders concluded implicit approach inquiry oriented approach was not very effective in enhancing students' views of NOS. Koseoglu and Yesiloglu (2010) in their study with 26 students concluded implicit approach lacked in improving students' understanding of most of the aspects of NOS except tentativeness and creativity. The ineffectiveness of the implicit approach in enhancing students' views of NOS is due to the assumption that students would automatically develop understanding of NOS as a by-product of engagement in science based inquiry activities or science process skills instruction.

3. Explicit Approach

Research has consistently shown that the inquiry-oriented curricula and research interventions were ineffective in enhancing students' views of NOS (Meichtry, 1992). Many science educators have noted that explicit approach is appropriate instructional approach to enhance students' understanding of NOS. (Khishfe and Abd-El-Khalick, 2002; Bell, Lederman, and Abd-El-Khalick, 2000; Khishfe and Abd-El-Khalick, 2002; Khishfe and Lederman, 2006; Akerson, Abd-El-Khalick, and Lederman, 2000).Bell, Matkins, Gansneder (2011:415) stated that "The explicit approach seeks to intentionally draw students 'attention to targeted aspects of the nature of science through discussion, reflection, and specific questioning in the context of activities, investigations, historical examples, and analogies." Further, Abd-El-Khalick and Lederman (2000) point that understanding of NOS should be taken as cognitive learning and it should be taught explicitly with proper planning, keeping in mind the anticipated learning outcome at the end of the lesson.

In explicit and reflective instructions, objectives are clearly mentioned in the lesson and the students are reminded and evaluated on what is their understanding about the nature of science. Many science educators have found the explicit approach more effective. In explicit and reflective inquiry approaches, the aspects of NOS are paid attention and planned to be imparted to the students in the objectives, instructions and in the assessments. Explicit and reflective inquiry oriented approach is planned to intentionally draws learners' attention through the discussion followed by reflecting aspects of NOS along with the engagement in the activities (Schwartz *et al.*, 2004). This provides an opportunity for the students to reflect on the aspects of NOS that has been emphasized on that particular context of science based activity or the science content (Khishfe and Abd-El-Khalick, 2002).

Akerson, Abd-El-Khalick and Lederman (2000) assessed the influence of reflective activity based approach with 50 undergraduate and graduate students enrolled in science teaching method course. They noted the significant changes between the pretest and the post. Students at the beginning of the course had inadequate conception on NOS however, after the instruction students showed significant gained in understanding tentative nature of scientific knowledge, the difference between theories and laws, and the difference between observation and inference.

Another empirical study conducted with 62 grade six students by Khishfe and Abd-El-Khalick (2002) showed the effectiveness of explicit inquiry oriented approach of instruction. The participants who experienced explicit inquiry oriented approach showed adequate understanding of NOS and concluded the inquiry oriented activity alone is insufficient to enhance student understanding of the nature of science, explicit reflective instruction is essential too.

Khishfe (2008) concluded explicit inquiry oriented approach showed effectiveness in enhancing students' views of the NOS in some of the aspects. However, the study did not show much improvement in observation and inference aspect of NOS which was also similar to findings of researchers (e.g., Akerson, Abd-El-Khalick, Lederman, 2000; Brickhouse, Dagher, Letts, and Shipman, 2000).

Akerson and Hanusin (2007) in their study found that teachers' explicit NOS instructions had helped elementary students to developed more informed views of NOS and they pointed out the explicit and reflective instruction can influence both students' and as well as teachers' views of NOS

In this study explicit and reflective approach was employed as many science educators in their empirical studied has found out explicit and reflective inquiry is most effective to teach NOS to the students and teachers.

Assessments in Nature of Science

The development and assessment of students' and teachers' understanding of NOS has been a concern in the science for more than fifty years and until late 1990s. In the past the assessment of NOS for teachers and students were standardized forced choice, paper and pencil test that comprise of force choice items such as multiple choice, true or false, agree, disagree and Likert type.

Some of the assessment tools used in the empirical studies are Test on Understanding Science (TOUS) developed by Cooley and klopfer (1961). It consist of sixty multiple choice test. Lederman, Wade, and Bell, (1998) argue that TOUS is not found to be an appropriate tool for assessing understanding of NOS but was an excellent at the beginning for those who had interest in assessing the understanding of NOS.

Views of Science-Technology-Society (VOSTS) developed by Aikenhead, Ryan and Fleming (1989) was one of the most commonly used assessment tool in the past. It consists of 114 multiple-choice which addressed numerous science technology society questions. It was developed based on the answer given by the students and validated with grade 11 and 12 Canadian students. Lederman, *et al*. (2002), argue that standardized paper and pencil test would in fact end up imposing the developers' views on the respondents rather than the respondents' views ,which could be bias in the part of the researcher. Moreover, there is ambiguity in the validity of the instrument.

Now, the leading assessment tools to assess students' and teachers' views of NOS is the Views of Nature of Science questionnaires (VNOS) developed by Lederman, *et al.* (2002) with high validity and reliability. VNOS assessment tool has many forms (e.g. Form A, B, C, and D) as per the level understanding of the respondent. Among the form A, B, C, and D the most widely used is VNOS C because it could be used for the teachers, under graduate and the students from grade 9–12. Lederman, *et al*. (2002) argues that the open-ended questionnaire in conjuncture with semi-structured interviews would lead towards achieving more valid and meaningful assessments of the students' and teachers' views of NOS. This assessment tool provides opportunity for the respondents to express their own understanding of NOS without imposing the developers' views of NOS on the respondents.

However, Liang, Chen, Kaya, Adams and Ebenezer (2008) pointed out that while using VNOS some challenges are faced by respondents with limited knowledge of NOS and limited writing skills whereby they may not be able to fully express their own ideas, which limits the potential of using VNOS instruments alone as either formative classroom assessment forms or accurate research tools. Moreover, the VNOS instrument may not be appropriate to assess a large number of the participants' view of NOS. Students Understanding Scientific Inquiry (SUSSI) is another assessment tool for assessing understanding of science developed by Liang *et al.*, (2008). The instrument was developed based on existing instruments including the VOSTS (Aikenhead and Ryan, 1992) and VNOS (Lederman *et al*., 2002). The development took place in four phases. The qualitative and quantitative nature of SUSSI instrument is unlike other force choice questionnaire, it can be used to effectively assess students' partial understanding of certain NOS issues and it is less time consuming. SUSSI can be used as a summative assessment tool to measure students' achievement in their understanding of NOS related issues. SUSSI has focused on six aspects of NOS namely observations and inferences; change of scientific theories; scientific laws versus theories, social and cultural influence on science; imagination and creativity and methodology of scientific investigation. The final version of SUSSI consists of 24 Likert-type item questions and 6 open ended questions. Each concept has four close-ended questions with range from strongly disagree to strongly agree followed by open-ended. Respondents can select their responses given in the Likert format and then explain what they actually understand about NOS (Liang *et al*., 2008). The developers have investigated and established the reliability of the instrument with international pre-service teachers and undergraduate students of USA, China and Turkey. The quantitative feature of SUSSI allows the use of inferential statistic to determine any instructional intervention in large scale and small scale.

Since there are lots of critical concern shown about the use of traditional paper and pencil approach because of an ambiguity regarding the validity of the instruments as the instruments and it imposes researchers' views to the respondents (Abd-El-Khalick and Lederman, 2010). Looking at the several draw backs of the assessment tools used in the past, in this study a combination Likert-types items and open-ended questions was used to assess the students' views of NOS. Moreover, the present study had a large number of participants an open-ended questionnaire was not practical.

CHAPTER III

RESEARCH METHODOLOGY

Overview of Chapter

This chapter first provides information about research phase and research design, population and sample size, sampling technique, development of instrument, data collection, data analysis, development of intervention units and ensuring Trustworthiness of data collection and analysis.

Research Paradigm

The purpose of this section is to describe, discuss and justify the research methodology and method implemented in the study. Methodology is the best way to gain knowledge of the world (Lincoln and Guba, 2000). Research methodology is a systematic way that guides a researcher to gather information and solve the research problem. According to Lincoln and Guba (2000: 164) "Methodology is inevitably interwoven with and emerges from the nature of particular disciplines such a sociology and psychology and particular perspectives such as Marxism, feminist theory and queer theory."

According to Martens, (2005: 7) "Paradigm is a way of looking at the world. It is composed of certain philosophical assumptions that guide and direct thinking and action." Research paradigm are divided into three main topics as positivist paradigm, interpretive paradigm and critical paradigm. A quantitative researcher mostly uses a positivist paradigm. Positivist researcher views that social reality is stable and patterns are seen and known through investigation, which starts with a theory and then the development of hypothesis. Interpretive paradigm view there is no social reality (Bailey, 2007). The researcher is interested in the meanings symbols, belief and ideas. In "Critical paradigm researchers also belief that there is no single reality and those works under this paradigm focus on the social reality is shaped by historical, social, political, cultural and economic factors." (Bailey, 2007: 55).

Every researcher does not look at the same thing from the same lens because they do not have similar beliefs, views on what they experience and how they interact within their surroundings and therefore researches differ from one another as it is govern by individual and subjectivity which results in conducting research studies in different paradigm. For instance, a researcher in an interpretive paradigm will focus to understand the meaning people have constructed about their world and their experiences and how people make sense of their experiences (Merriam, 2002). On the other hand, positivist researcher will focus on generalization and abstraction whereby their thought is governed by hypotheses and stated theory (Bailey, 2007). In order to be sure and clear the researchers' way of looking at the world, a methodological choice and exploration of paradigm need to be specified in his/ her study depending upon ones' own belief in the research paradigm.

Interpretive research methodology is chosen to be the research paradigm in this study. Stake, (2010: 36) defines interpretive research as an "Investigation that relies on observers defining and redefining the meanings of what they see and hear." The main aim of an interpretive researcher is to understand the human behavior and try to interpret their behavior without generalization and prediction of cause and effects as the researcher tries to and understand motives, meaning and the reason (Hudson and Ozanne, 1988). Similarly, Faikhamata (2007) stated that interpretive researchers are believers of realities which cannot be isolated from their context such as environment, classrooms, community, and school. Interpretive researchers are in view that there is no reality but the reality has to be constructed and the knowledge has to be then interpreted. The central goal of interpretive paradigm is to mainly understand the subjectivity of the world and to get inside the persons and understand them.

Although the researcher used both qualitative and quantitative data and survey in the phase 1 to find out the baseline for the second phase, the main aim of this study is to investigate how can explicit and reflective inquiry approach influence ninth grade Bhutanese students' views of NOS. In this study the researcher is the teacher as well, where the researcher can directly experience, understand and build her theory on the students understanding of NOS through an explicit and reflective approach. Here the researcher is interested to understand and see the development of students in the classroom and make sense of individual students' views of NOS from multiple data sources and interpret it. Interpretive paradigm helps the researcher to obtain knowledge by investigating the influence of explicit and reflective approach through integrating NOS in chemistry lesson, and interpreting what they have actually understood within stipulated time period.

Research Phase and Research Design

As mentioned earlier this study is divided in two main phases. In the phase 1, survey research design was employed to answer what are the views of NOS among ninth grade students? Results obtained from the survey was used as the baseline to develop the chemistry lesson in ninth grade integrating aspects of NOS to further deepen student understanding of NOS through case study research design in the second phase answering the second question; how does explicit and reflective approach influence grade nine students' views of NOS?

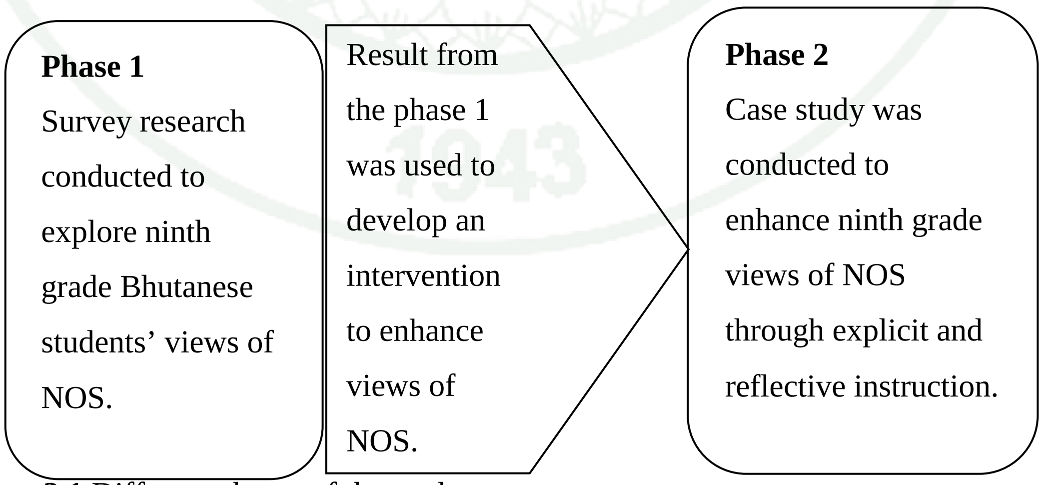

Figure 3.1 Different phases of the study

Phase 1: Survey

"A survey is a systematic method of gathering information from a sample of entities for the purposes of constructing qualitative descriptors of the attributes of the larger population of which the entities are members" (Groves *et al.*, 2004: 2). In this study survey design will be used to answer what are the views of NOS among ninth grade students?

Population and Samples

Population in this study comprise of ninth grade students of middle secondary and higher secondary schools in Bhutan. The total student population in ninth grade in twenty districts counts to 12,816 in 102 schools from both middle secondary schools and higher secondary schools (PPD, 2013). All schools in Bhutan follow a single national curriculum and the same school syllabus. Text books and relevant teaching learning materials are developed and supplied by the Ministry of Education to the schools (Ministry of Education, 2012).The quality control and the monitoring, appointing heads of the schools, reshuffling of teachers in the districts are done by the government. Further, teacher deployment is done by the government as per the requirement of the schools which shows that each student throughout receives similar kind of education despite of the geographical barriers in which some schools may not have the same facilities.

To determine the sample size, Taro Yamanes' (1963) table and formula was used, where 390 out of 12,816 populations randomly selected with 95 percent confidence, an acceptable level in educational research. Sample size is calculated using the Taro Yamane Formula

$$n = \frac{\mathrm{N}}{1 + \mathrm{Ne}^2}$$

Where: n is the sample size

N is the population size (total number of grade nine students in Bhutan

e is the significant level (0.05)

$$n = \frac{\mathrm{N}}{1 + \mathrm{Ne}^2}$$

$$\frac{12816}{(1 + 12816\,(0.05)^2)} = 389$$

Sampling Technique

Stratified random sampling method was used to find out the representative of the population. Bhutan is divided in four regions, namely eastern, western, southern and central due to its geographical location. Each region was considered as strata. From each strata depending upon the number of students from regions, schools were simple randomly sampled with an assumption that each section of grade comprise of 30 students. Further, one section of grade nine from a these schools were randomly sampled to be the participants of this study. In total, fourteen schools from middle secondary and higher secondary schools participated in this study.

Table 3.1 Proportional sampling technique for ninth grade students of Bhutan

Regions	**Number of Schools**	**Number of students**	**Number of schools from each region**	**Estimated number of students in with an assumption each class has 30 students**	**Minimum sample based on proportion from each region**
Central	19	2,376	3	90	73
Southern	15	1,882	2	60	57
Eastern	30	3,580	4	120	108
Western	36	4,978	5	150	151
Total	102	12,816	14	420	389

Source: PPD (2013)

Development of Instrument

Students' Understanding Scientific Inquiry (SUSSI) is an assessment tool for assessing understanding of nature of science and scientific inquiry developed by Liang *et al.*, (2005, 2008). The instrument was developed based on existing instruments including the VOSTS (Aikenhead and Ryan, 1992; VNOS Lederman *et al.*, 2002). SUSSI focuses on six aspects of NOS namely observations and inferences; change of scientific theories; scientific laws versus theories, social and cultural influence on science; imagination and creativity in scientific investigations and methodology of scientific investigation. The final version of SUSSI has 24 Likert-type item questions and 6 open-ended questions. Each concept has four close-ended which ranges from strongly disagree to strongly agree followed by open-ended. Students are to select their responses given in the Likert format and then explain what is their actually understanding of NOS and scientific inquiry with examples (Liang *et al*., 2008).The development had taken place in four phases. The qualitative and quantitative nature of SUSSI instrument is dissimilar other force choice questionnaire as it can be used effectively assess students' partial understanding of certain NOS issues. In addition, SUSSI can be used as a summative assessment tool to measure students' achievement in their understanding of NOS. The developers have investigated and established the ratability of the instrument with international pre-service teachers and undergraduate students of USA, China and Turkey. The quantitative feature of SUSSI allows the use of inferential statistic to determine any instructional intervention in large scale and small scale and allow it to be less time consuming (Liang *et al*., 2005; 2009).

Liang *et al.* (2009) pointed out that a questionnaire consisting of only open-ended questions would allow many students to leave questions blank without answering or may answer in few words which could undermine the quality of a study. Park (2012) cited Brown (2007) has identified that there is important cultural difference in writing and answering open-ended questions. For example, Asian cultures value indirect descriptions while western culture prefers a direct approach when students answer open-ended questions. Similarly, if the students are assessed understanding of NOS, with open-ended assessment tools then there might be ample chances that many students may not be able to express what they know and thereby leave the questions unanswered which would undermine the quality of the study. Keeping all these factors in ones' mind I, as a researcher, have adopted and adapted the existing SUSSI to assess views of NOS ninth grade students of Bhutan.

Since SUSSI had been tested with under graduate students and has been used for teachers to assess their understanding of NOS and scientific inquiry, it was necessary to change some words and sentences. Therefore, before adopting and adapting, SUSSI instrument was tried out with ten ninth grade students of one of the middle secondary schools of Bhutan. Based on students' feedback some words and the structure of the sentences of the questionnaire were changed. For example, some words like 'prior knowledge' was changed to earlier experiences; scientists are *objective* was changed to scientists think *in the similar way*. Some phrases like 'Scientific theories may be changed because scientists reinterpret existing observations' was rephrased as 'a new interpretation of data can change our present scientific theories' without altering the meaning. To the existing SUSSI, the empirical nature of scientific knowledge is added which all together consists of seven aspects nature of science.

Since, SUSSI has been already well validated by nine panels of nine experts Liang *et al.* (2005). In the adapted version some alteration in the words into simpler sentences suitable grade nine level of understanding and one more aspects of science was added to existing one. To ensure the content validity of the instrument, the items were examined by three experts including the original developer of the SUSSI and two science teachers who teach grade nine students in Bhutan. Further, to ensure the reliability of the instrument, a pilot study was conducted with 37 students in two schools in Bhutan. A sample of research instrument is shown below on Table 3.2

Table 3.2 Sample of Likert scale and open-ended questionnaire

1	**Observations and Inferences**					
A	Scientists' observations of the same event may be different because the scientists use earlier experience and knowledge may affect their observations.	SD	D	U	A	SA
B	Scientists' observations of the same event will be the same because scientists think in the similar way.	SD	D	U	A	SA
C	Scientists' observations of the same event will be the same because observations are facts.	SD	D	U	A	SA
D	Scientists may make different interpretation based on the same observations.	SD	D	U	A	SA
After scientists develop a scientific theory (for example, cell theory, atomic theory, evolution theory, etc.) does the theory ever change? With examples, explain why you think scientific theories do not change OR how (in what ways) scientific theories may be changed.						

Note: SD=Strongly disagree, D=Disagree, U=Uncertain, A=Agree, SA=Strongly agree

Source: Liang *et al*. (2008)

Data collection

The existing Student Understanding of Science and Scientific Inquiry (SUSSI) developed by Liang *et al*. (2005) was adopted and adapted to explore ninth grade views of NOS. Each aspect of NOS has four Likert-type items, with common naïve and informed views and open-ended questions. A combination of 28 Likert-type item and 7 open-ended research questionnaire were used as a research instrument to explore the students' view of NOS. The open-ended questions were adopted from Lederman *et al*. (2002) and Park *et al*. (2012) along with the SUSSI open-ended questions. To obtain correct information, questionnaires were appropriately designed and distributed to the students who were then asked to complete the survey questionnaire in the class under the supervision of the teacher, and without using any resources such as textbooks or discussion with friends. Further, in accessible schools the researcher has herself supervised.

Data analysis

Data collected were analyzed both using qualitative and quantitative measures. The positive (+) ones are the views that are consistent with the current international science education reform documents, negative (-) ones represented students' naïve views on the different aspects of NOS. For each positive response, points were given from 1 to 5. For example, strongly disagree response=1, disagree=2, uncertain=3, agree=4 and strongly agree=5. For each negative response in the scale the scores were assigned in reverse ordered from 5 to 1. For example, strongly disagree =5, agree=4, uncertain=3, agree=2 and strongly agree=1. Scoring rubric was adapted from original developer Liang *et al*. (2009). A new code 1, 2, 3 was given by each theme and the students' response were categorized as naïve views (1) if none of the four responses scored more than three; transitional (2), if one or more than one (but not all) of the four responses are either more, equal to or less than less than three; and informed views (3) if all of the four responses received more than 3.

Table 3.3 Scoring guide for evaluation of Likert scale

Naïve views (1)	Transitional views (2)	Informed views (3)
If none of the four responses scored more than three.	If one or more than one (but not all) of the four responses are more, equal to or less than less than three.	If all of the four responses received more than 3.

Source: Adapted from Liang *et al*. (2005, 2008)

Analysis of open-ended responses of all the students were not possible due to large number of the participants, so about 25% of the students' responses from each school were randomly picked up at first and then analyzed looking for the pattern to develop theme. To ensure the reliability of the data collected, researcher firsts analyzed all the data independently and all the analyzed data were reviewed by the supervisor. Differences in the interpretation were resolved through further discussions until the consensus. For the open-ended question, scoring rubrics guide used for this study was adapted from Liang *et al.* (2008) and Lederman *et al.* (2002). In addition, with consultation of supervisor and science educators, students' open responses were classified into four categories based on the rubrics, providing a score for each categories as non-classifiable (0), naïve (1), transitional (2) and informed views(3). If students did not respond, or wrote sorry madam, don't know or if the response written were not answering that particular to question were classified as non-classifiable. Responses that showed misconception and self-contradiction statements were classified as naïve. If the students showed partially informed views without any justification, or if the students provided unrelated examples were classified as transitional views. Finally, if the students' responses were consistent with the schools of contemporary thoughts, it was classified as informed views.

Table 3.4 A scoring guide for evaluating open-ended responses

Non-Classifiable (0)	**Naïve View (1)**	**Transitional views (2)**	**Informed View (3)**
If there were no response or students state that they do not know the answer; sorry madam; or the response cannot be classified based on the rubric descriptions.	If there were misconception or self-contradicting statements	If the responses showed partial informed views without any justification or if the students provided unrelated examples.	If the responses were consistent to the contemporary thoughts on each aspects of NOS.

Source: Adapted from Liang *et al.* (2008)

Phase 2: Case study

A case study is a detailed examination designed to gain an in-depth understanding of a particular unit or bounded system such as an individual, program, event, group, intervention, or community and gather enough information in systematic way that allows the researcher to effectively understand how the subjects operates or function (Bogdan and Biklen, 2003; Berg, 2009; Merriam, 1998). Case study can also support the study “to understand processes of events, projects, and programs and to discover context characteristics that will shed light on issues or object” (Merriam, 1998: 33). Further, Mertens (2005) points out that some cases like an organization, a classroom, a clinic or a neighborhood are more complex and it becomes harder to define the individual, in this type of cases the researcher have to base their design on either single case or multiple case. The researcher needs to establish the boundaries as clearly as possible in terms of participants, the geographical area, and time for beginning and ending the case.

Case study research design is chosen to answer how does explicit reflective inquiry approach influence grade nine Bhutanese students’ understanding of NOS? As the selection of the case study is determined by the purpose and the research question and it includes the collection of the data from the individual case or from the organization. In addition, a case study is particularly useful when the researchers need to understand a unique situation and it provides a clearer picture about the unique example of real people in a real situation rather than the abstract theories and the principles (Chohen, Lawrence and Morrison, 2000).

Participants

Participants in this phase were students from one of the higher secondary schools which comprised of 1,100 students in total. This school had three sections of ninth graders with a total of 56 students. Two sections comprised of 18 students each and one section had 19 students. From these three sections, one section was randomly selected to be participants of this study. This particular school was selected as per the convenience and proximity. Moreover, the researcher had worked as teacher in this school for 9 years and the participants were taught by the researcher in the lower grades. All these factors made it more feasible and allowed the researcher to profoundly understand each student.

Development of Intervention Unit and Implementation

As mentioned earlier in chapter two, scientific literacy is one of the main goals in science education. Bhutan too wants its citizens to be scientifically literate taking into account the development as experienced by nations around the world to achieve scientific literacy underpinned by GNH principles. The new science curriculum has stressed the development of investigative skills through approach that opposes the old traditional ways of teaching methods that emphasized on memorization of facts It has proposed constructivist approach of teaching that involves identification of students' prior knowledge, experiences, views, modify and reconstruct his or her ideas based on their preexisting conception. In the new science curriculum, how science works has been merged as 'working scientifically' and students at the end of each key stage are expected to have learned how science works from their involvement in designing investigations and experiments; gathering and communicating evidence; planning, concluding and evaluating automatically (DRCD, 2012).

As mentioned earlier the implementations of new science curriculum has begun in grade 4, 5, 6, and 7 and for grade eight and above are supposed to be implemented in the coming subsequent years. When this study was conducted, students were still following the old science curriculum. The researcher integrated NOS in old syllabus ninth grade chemistry in two units. Since NOS is quite new in Bhutan, survey on ninth grade views of NOS was conducted phase 1. Phase 2 of this study was an intervention developed to enhance ninth grade Bhutanese students' views of NOS based on the results obtained from the phase 1. During the intervention seven aspects of NOS namely: tentativeness of scientific knowledge; the empirical nature of scientific knowledge; observation and inference; creativity and imagination; scientific theories and laws; scientific methods and social and cultural embeddedness were integrated in two units of ninth grade chemistry course in Matter and Its Composition and Gas Laws in ninth grade. Although, many science educators and researchers (e.g., Ad-El-Khalick *et al*., 1998; Bell, Lederman and Abd-El-Khalick, 2000; khishfe and Lederman, 2006) pointed out that scientific laws and theories and social and cultural embeddedness aspect of NOS are difficult for pre-service teachers to understand as well and for the students is out of question. Though it is difficult for the students to understand scientific laws and theories and social and cultural embeddedness aspect of NOS, this study focused to develop students' views in seven aspects including scientific laws and scientific theories and social and cultural embeddedness taking into consideration the learning outcome that the students should achieve at the end of ninth and tenth grade and as per the nature of the content taught. For instance, in ninth grade, students learn scientific laws and scientific theories and for the social and cultural embeddedness aspect of NOS one of the objective that the students must achieve by the end of ninth and tenth grade is that they should be able to "give examples of the ways in which scientific work may be affected by the social, historical and cultural contexts in which it takes place and how these contexts may affect whether theories and ideas are accepted" (DRCD, 2012: 23).

The main aim of the study is to enhance students' views of NOS and in order to develop Bhutanese students' views of NOS to informed views an intervention was carried out in the beginning of the academic year of 2014 based on the results from the survey result of the phase 1. During the intervention the lessons were taught for 55-minutes per session for duration of 6 weeks. Prior to the intervention, seven lessons plans were developed based on constructivist approach integrating aspects of NOS in the content and then lessons were critically reviewed by three experts. In this study different approaches like historical cases, content related inquiry activities, and decontextualized activities were employed to teach different aspects of NOS depending upon the nature of the content as suggested by many researchers. For instance, Khishfe and Abd-El-Khalick (2002) concluded students' NOS views could be enhanced when the aspects of NOS are embedded and taught through content related inquiry activities. Similarly, Akerson *et al*. (2000) suggested that the roles of subjectivity, social and cultural actor, in science are best learned through rich historical case studies which would be more effective in science content course. Clough (2006) argue that an explicit decontextualized NOS instruction play an important role in drawing students' attention to particular NOS issues and initiating deep cognitive processing. Furthermore, a decontextualized activity can provide a solid foundation that can link contextualized NOS instruction.

During the intervention a constructivism learning approach was used as a teaching strategy which gave students an opportunity to make connection between what they already know and the present learning through a demonstration activity. It helped the students to focus on the learning outcome of the current activity and help the students to mentally engage in the concept, and enhance skills that can help them to further explore the concept in depth. Students were given questions to be explored and the students had to design a procedure to find out an answer to the questions that was provided. In the process of experimentation, students learned organizational skills that are required in the scientific investigation such as organizing procedures, noting observations, managing data tables, being honest about their data, how they could make their data more reliable and accurate, interpreting data, drawing conclusions and report their findings to other friends which helped them to understand the importance of collaboration and sharing ideas. Throughout the intervention students worked in pairs or in groups of four members each. The summary of the topics, activities and aspects of NOS under taken over the course of intervention is presented in Table 3.5.

Table 3.5 Activities and the aspects of NOS integrated in each lesson during intervention

Lesson No.	Units	Duration (minutes)	Topics	Activities carried during the lesson	NOS aspect integrated
1	Matter and its Composition	110 minutes	Early ideas about the composition of matter	-Time line of different philosophers/ scientists like Epodolecles,	-Tentativeness -Social and cultural embeddedness

Table 3.4 (Continued)

Lesson No.	Units	Duration (minutes)	Topics	Activities carried during the lesson	NOS aspect integrated
1	Matter and its Composition	110	Composition of matter	Democritus, Aristotle John Dalton's ideas about composition	- Creativity and imagination
2.	Lesson developed to teach scientific method based on the feedback from lesson 1.	110	Scientific method	-Candy and Soda activity	-Scientific method
3	Matter and its composition	110	Motion in liquids	-Students design an experiment to investigate -Motion of molecules -Watching video clips	-Empirical Creativity and imagination
4	Matter and its Composition	110	Change in states Students of matter inter-conversion of the states of matter	-Observed phase changes in different station	-Observation and inference
5	Matter and its Composition	165	Law of conservation of mass	-Students designed an investigated to law of conservation of mass -Watching video clips	-Creativity and imagination -Scientific laws

Table 3.4 (Continued)

Lesson No	**Units**	**Duration (minutes)**	**Topics**	**Activities carried during the lesson**	**NOS aspect integrated**
6	Study of Gas Laws	165	Lesson Boyles' law	Students investigate the relationship between volume and pressure through guided inquiry learning.	-Scientific theories and scientific laws. -Empirical Tentativeness
7	Study of Gas Laws Charles' law	165	Charles' law	Students investigate the relationship between volume and temperature through guided inquiry learning.	-Scientific theories and scientific laws.

Source: ISCE chemistry for class IX Chugh (2010)

Data collection

To enhance Bhutanese ninth grade students' views of NOS, a case study was designed that involved the use of multiple data source. The multi data source includes the same questionnaires used in phase 1, semi-structure interviews, students' journals, students' assignments, observation and teachers' reflective journals. The details of the collection of data using different sources are discussed below:

Questionnaire

The questionnaire developed were designed to explore students' views of NOS in seven aspects: tentativeness nature of scientific knowledge; the empirical nature of scientific knowledge; observation and inference; creativity and imagination; scientific theories and laws; scientific methods and social and cultural embeddedness. SUSSI developed by Liang *et al*. (2008) was adopted and adapted to explore ninth grade students' views of NOS. Each theme consisted of four Likert-items, with common naïve and informed views and open-ended questions. A combination of 28 Likert-type items and 7 open-ended research questionnaire were used as a research instrument to explore the students' view of NOS. The open-ended questionnaire was adopted from Lederman *et al*., (2002) and Park *et al*., (2012) along with the SUSSI open-ended questions. SUSSI has been already well validated by a panel of nine experts (Liang *et al*., 2008). In this version some alterations in the words into simpler sentences suitable for grade nine level of understanding and one more aspects of NOS was added to the existing SUSSI. To ensure the content validity of the instrument, the items were examined by three experts including the original developer of the SUSSI and two science teachers who teach grade nine students in Bhutan. A pilot study was conducted with 37 students of one of the middle secondary schools in Bhutan to validate the reliability of the instrument. A questionnaire was administered before and after the intervention. To obtain an accurate data a questionnaire was distributed to the students whereby students completed the questionnaire in class without using any resources such as a textbook and without discussing with their friends under the supervision of the researcher herself.

Students' Journal

Students were asked to write reflective journal which gave an opportunity for the students to think about their learning and it encouraged them to reread and revise what they have learnt. From the students' reflective journals, researcher got information about what was not clear from the lessons taught. It also helped the researcher find out the misunderstandings and confusions and clarify the same.

Classroom observation

Observation is one the powerful data source in an interpretive research. Observations are used to gather accurate information about how a program activity actually operates, particularly about the processes involved. In this study, since researcher was a teacher as well, to take field notes were not possible however, every lessons taught during the intervention were videotaped which ensured the trustworthiness of the data through prolonged engagement. A video recorder was used in every lesson taught which enabled the researcher to review the events in the classroom like how much did the researcher responded to students' talks, whether instructions and explanations were clear or not and in which activity aspects of NOS were difficult for the students to understand? It also helped the researcher to reflect on her teaching and identify the weakness and strengths. To increase the trustworthiness of observation, before recording the classroom observation students were given information about the reason of recording so as not to get them intimidated.

Semi-Structure Interviews

Interviews are one of the data source in an interpretive research. Before the students were interviewed, students were asked their views about the topics and told it would not affect their scores. They were made to feel at ease regarding the nature and purpose of the interview. It was conducted one week after completion of both pre-instruction and post-instruction questionnaires to further probe the students' views of NOS especially for the students who did not write the answers. This allowed the researcher to examine whether students' responses in the semi-structure interviews were consistent to what the students expressed in the pre-instruction and post-instruction questionnaires. All the interviews were audio taped.

Data Analysis

Phase 2 of this research was focused to examine how explicit and reflective approach enhances Bhutanese students' views of NOS. The analysis of data collected from the pre-instruction questionnaire and post-instructional questionnaire were analyzed in four steps. In the first step the data Likert-type items were categorized in three categories i.e., naïve, transitional and informed views using a guiding rubrics adopted and adapted from Liang *et al*. (2008). A new code 1, 2, 3 was given by each theme, the students' response were categorized as naïve views (1) if none of the four responses scored less than three; transitional (2), if one or more than one (but not all) of the four responses are either more, equal to or less than less than three; and informed views (3) if all of the four responses received more than 3. Percentages in each category (naïve, transitional, and informed views) were calculated.

In the second steps the open-ended questions the students responses were categorized into four categories (Non-classifiable, naïve, transitional and informed views) based on the rubrics developed (see appendix D) from the original developer and the Lederman, *et al*., (2002). Students' open responses were classified into four categories based on Liang *et al*., (2008), providing a score for each category as non-classifiable (0), naïve (1), transitional (2) and informed views (3). If students did not respond, or wrote sorry madam, don't know or if the response written were not answering that particular to question were classified as non-classifiable. Responses that showed misconception and self-contradiction statements were classified as naïve. If the students showed partially informed views without any justification, or if the students provided unrelated examples were classified as transitional views. If the students' responses were consistent with the schools of contemporary thoughts, it was classified as informed views. Interviews were transcribed to see when the responses from the open-ended responses were ambiguous. Then, percentages in each category were calculated.

In the third steps the entire open-ended responses were reread to come up with patterns and themes for each aspect of NOS. To ensure the reliability of the data collected, researcher first analyzed all the data independently and all the analyzed data were reviewed by the supervisor. Differences in the interpretation were resolved through further discussions until the consensus. In the fourth steps, the video records from the classroom observation for each period were transcribed word by word to see the teachers teaching to avoid bias. The dialogue where aspects of NOS were explicitly discussed were pulled to show as an evidence to support the claim that explicit and reflective inquiry approach can enhance Bhutanese views of NOS. In the fourth steps all the classroom observations for every period were transcribed lesson and coded to build the themes.

Ensuring Trustworthiness of Data Collection and Analysis

Merriam, (1998) stated that qualitative researchers are the primary instruments for the data collection and analysis, because the interpretation of reality are accessed directly through observation and interviews. Trustworthiness of data collection and analysis is now discussed to show the quality of the research study reported here. In order to ensure trustworthiness in the interpretive research, Lincoln and Guba, (1985) have proposed four criteria namely: credibility, transferability, dependability and conformability.

Credibility

Lincoln and Guba (1985) proposed credibility in quality research instead of internal validity. According to Merriam, (2002) credibility in qualitative research ask the question “how congruent are ones’ findings with reality.” In qualitative research, the understanding of the reality is truly depends really on the researchers’ interpretation of participants’ explanation or understandings of the phenomenon of interest. To ensure to credibility a researcher can ensured in several strategies. Some of the strategies a qualitative researcher can use are: prolonged and substantial engagement, Persistence observation, peer debriefing, member check and triangulation. Credibility in this research was increased through multi-methods of data collection and methodical triangulation the data. Students' journal, observation, teachers' self-reflection were brought together and analyzed to examine. To ensure the credibility in this study, data were collected from the multiple sources and were triangulated. Prolong engagement, in which all the classroom teaching were recorded and observed in each period to see the development and in addition, as mentioned earlier, the researcher had worked in the same school for 9 years that has helped her to understand deeply the development of students' views of NOS during the intervention.

Transferability

Lincoln and Guba (1985); Merriam, (1998) points out a thick description, is a credibility technique, that assists others in their understanding of the findings in the study and in their assessment of the transferability of the findings to other situations providing rich, thick description is a major strategy to ensure for external validity or generality in this study, a thick description of the context of the study was used to increase the trustworthiness of the study. The school where this study was conducted is located in the western region of Bhutan. The student strength over the years has grown steadily and currently there are about 1,030 students from different socio economic background in 32 sections, 52 teachers and 13 support staff. So far, 13 batches of class 10 and 4 batches of class 12 have graduated from this school. The school has three science laboratories for different discipline of science and are spacious enough to fit about 32 students. Each laboratory has one lab assistant appointed. The school also has two computer laboratories with one LCD projector and internet facilities. When teachers want to show video clips or show documentary, the students are taken to the computer laboratory.

During the intervention, the chemistry laboratory, computer laboratory and the classroom were used to suit the lesson depending on the nature of the content taught in that particular period. For instance, the lessons on the composition of matter with the time line were taught in the classroom and lesson with the videos clips were taught in the computer laboratory but most of the lessons were taught in the in chemistry laboratory as it required experimentations.

Dependability

Dependability is parallels reliability. It is a technique that shows whether the work is repeated within the same context using the same method (Shenton, 2004). It is suggested that researcher should keep complete records of all phases of the research process, from problem formulation to data analysis decisions, in an accessible manner. Entire lesson taught during the intervention were videotaped and discussed with the supervisor.

CHAPTER IV

RESULTS AND SUMMARY

This chapter presents the results of the study from phase 1 and phase 2. The results are organized in two parts i.e. results from the phase 1 from a survey research that intended to explore views of NOS among ninth grade Bhutanese students. The results obtained from the survey was used as the baseline to develop the chemistry lessons in grade nine integrating seven aspects of NOS to further deepen student views of NOS through case study research design in phase 2. Two chapters from grade nine chemistry syllabus namely Matter and its Composition and Gas Law were taught during the intervention to enhance students' views of NOS. The guiding question for Phase 1 and phase 2 are mentioned below:

Phase 1: What are the views of NOS among ninth grade Bhutanese students?

Phase 2: How does explicit-reflective approach influence grade nine Bhutanese students' views of NOS

Result from Phase I

Results of the Ninth Grade Bhutanese Students' Views of NOS

To answer the Phase I question regarding the views of NOS among ninth grade Bhutanese students, a survey was conducted in fourteen schools from different regions of Bhutan towards the end of the academic session as mentioned in chapter 3. A questionnaire adopted and adapted from Student Understanding of Science and Scientific Inquiry (SUSSI) developed by Liang *et al*. (2008) was administered to explore initial views of ninth grade students. Each item in the questionnaire consists of four Likert-type items with common naïve and informed views and open-ended questions. Likert-type items were categorized into three categories namely: naïve, transitional and informed views while the open-ended responses were categorized into four categories namely: non-classifiable, naïve, transitional and informed views. The students' views of NOS in seven aspects such as tentativeness of scientific knowledge; the empirical nature of scientific knowledge; observation and inference; creativity and imagination; scientific theories and laws; scientific methods and social and cultural embeddedness were explored. The results from both Likert-type items and open-ended questions are shown clearly in Table 4.1

Observation and Inference

Likert scale showed that 87.9% of the students held transitional views and only 9.7% of the students held informed views, and 2.3% held naïve views in observation and inference according to our scoring rubric. Coming to individual Likert items, it was overwhelming to see that the majority of the students (80.2%) believed that scientists make different interpretations based on the same observation. Similarly, in the open-ended responses the majority of the students (69.4%) exhibited transitional views, 13.3% held naïve views, and 17.3% held informed views. Some of these students who held naïve views believed that scientists have the same observation and interpretation because the observations are facts and true. For example, one of the students responded:

> "Scientists' observation and interpretation are same because the observations are facts and real. All the facts and truth for the events will remain the same until the rule is changed by someone else." (S # 038)

> "I think scientists' observation and interpretation are same because when they observe the things they will see or study the same thing and they will get the same idea about it. For example, if one scientist is observing a cell and he says that it looked like a jail then another scientist will come observe it and he will also see the same thing that cell is like a jail." (S # 017)

Table 4.1 Number (n=98) and percentage of students holding naïve, transitional and informed in open-ended responses

Aspects of NOS	**Open-Ended Response**			
	Non-classifiable	**Naïve (%)**	**Transitional (%)**	**Informed (%)**
Observation and inference	0	13.3	69.4	17.3
Tentativeness	2.0	39.8	37.8	20.4
Scientific theories and laws	5.1	81.6	13.3	0
Social and cultural embeddedness	6.1	64.3	21.4	8.2
Creativity and imagination	3.1	15.3	72.4	9.2
Scientific method	15.3	35.7	42.9	6.1
Empirical nature of scientific knowledge	4.1	14.3	75.5	6.1

Table 4.2 Number and percentage of students holding naïve, transitional an informed in Likert scale (n=389)

	Likert scale		
	Naïve (%)	**Transitional (%)**	**Informed (%)**
Observation and inference	2.3	87.9	9.8
Tentativeness	2.6	85.9	11.5
Scientific theories and laws	18.3	81.7	0
Social and cultural embeddedness	29.8	68.4	1.8
Creativity and imagination	7.7	62.5	29.8
Scientific method	1.5	93.6	4.9
Empirical nature of scientific knowledge	8	90	2.1

On the other hand, some students believed that scientists' observation and interpretation are the same because scientists have the same qualification. For instance, one of them wrote:

> "Yes, I should say that scientists' observation and interpretation are same because many scientists have their same qualification. They are almost in correct way. Sometime only they come across wrong but all their observation comes true." (S # 025)

On the whole, majority of the students held transitional views. However, student responses from the open-ended questionnaire indicated the theory-laden aspects of both observations and inferences in science.

Tentativeness Nature of Scientific Knowledge

In the Likert part, the majority of the students held transitional views. Looking at the individual Likert-type items (see appendix D), more than 50 % of the students believed that "scientific theories are based on accurate experimentation and they will not be changed." Similarly, in the open-ended question majority of students about 39.8% held naïve views. These students were with an opinion that scientific theories do not change since theories have been experimented and proven with evidence. Students seemed to have absolutist views. Some of the students' responses are mentioned as follow:

> "After scientist develops a scientific theory like cell theory, atomic theory, etc., it cannot be changed because I think the scientists have done experiment base on theories which they have proved and it cannot be changed. For e.g. cell theory they have proved it with the three reasons."(S # 051)

> "After scientist develops a scientific theory will not change because it has be proven with so many tests and it is agreed by world only after strong proof and details." (S # 020)

Interestingly, there were some students who believed that scientific theory would not change as they are still learning what scientists have developed and that has been true for many years.

> "After scientists develop a scientific theory, it does not change ever because we are living and studying or learning what the scientists had discovered long back. All theories we learned in science area, are discovered long back ago by great scientists." (S # 043)

About 20.4% of the students held informed views in these aspects. Students' seemed to have more informed views in this aspect of NOS as compared to other aspects. Students believed that scientific theories changes were due to advancement in technology which brings in new evidences or reinterpretation of the existing evidence. The majority of the students gave example from the periodic table and the atomic theory.

> "After develop a scientific theory it can change by revision or more observation based on more observation based on particular things and new interpretation. Example, atomic theory in modern theory it says atom can split and in Dalton theory atom cannot be split." (S # 072)

The majority of the students held naïve views, Overall students thought that scientific theories or scientific knowledge would not change because scientific theories are proven with repetitive experiments; the students therefore seemed to hold absolutist views.

Scientific Theories and Scientific Laws

The result in distinction between scientific theories and scientific laws aspect of NOS appeared to be overwhelming. None of the students held informed views both in the Likert part and the open-ended response. In the subscale analysis, 75.1 % of the students believed scientific laws are theories that have been proven and 50% believed that scientific theories change but scientific law would not change. Similarly, in the open-ended questions, the majority of the students were with the views that scientific theories would change but scientific laws would remain the same as it is scientifically proven and true. For instance, some students responded:

> "Yes, there is a difference between a scientific theory and scientific law, science scientific law is proved and fixed and it will not change whereas scientific theory can change according to their observation and experiments. E.g. cell theory."(S # 019)

Another pattern noted was a common misconception regarding the relationship between scientific theories and scientific laws. Students believed that scientific laws are the scientific theories that have been proven. Some responses of the students are:

> "No, there is no difference between a scientific theory and scientific laws because according to scientific laws are scientific theories that are more proven. Gas laws which state that a gas has low density; gases cannot pour out from one container to another." (S # 045)

> "No, because scientific laws are theories that have been proven. E.g. cell theory is a unit of life and it is proven with diagram and providing the reference." (S # 078)

Interestingly, many students misinterpreted the word 'scientific law' as the 'rule' in the open-ended responses. Some of the students saw scientific laws as 'rule' that scientists follow during the scientific research. For example, one of the students wrote that "Scientific theories are given to follow procedure. Scientific law means the rules of science." (S # 084)

> "Yes, there is difference between scientific theory and scientific law. Scientific theory means when they are doing investigation, the result what they have got and scientific laws means a rule, while doing the same investigation at time they use it." (S # 034)

On the whole, majority of the students held naïve views and failed to see that theories and laws are two different kind of knowledge and has different functions.

Social and Cultural Embeddedness

With regard to social and cultural embeddedness of NOS, only 1.8% of the students held informed views in the Likert part. Coming to the individual Likert-type items, 50% of the students believed that science is not influenced by society and culture because scientists are trained to conduct pure unbiased studies. Interestingly, more than half (about 59.1%) of the students believed science is not influenced by cultural and societal values because science is independent of society and culture. Similarly, in open-ended responses majority of students (64.5%) held naïve views. From the common themes, it was seen that many students believed that scientific knowledge and research deals with nature, scientific truth and it is not affected by culture and society. For these students the work of scientists seemed excavating the truth and it is not influenced by social and cultural values as science is independent from the society and culture. Some of the students' responses are mentioned as follow:

> "No, because the social and cultural values are superstitious, they just the beliefs in cultural and religious societies. The work of the scientists is based on researches, experiments, investigation and many more. Scientist doesn't care about all these beliefs which don't make any sense." (S # 03)

> "I don't think that social and cultural values decide what scientist should work on because from my point of view science is not influenced by cultural and social values because science is independent of society and culture."(S # 043)

> "No, social and cultural values don't decide scientist should work because they are independent on their own. E.g. it is cultural that the status of Buddha is to be worship but not be researched or discovered on old things." (S # 064)

On the other hand, there were some students who believed that social cultural values does not decide the work of scientist because scientists are highly educated. For instance, one of the students stated that:

> "No, I think social and cultural values don't decide what scientists should work on because they are highly educated and they use their imagination and creativity to create new things."(S # 04)

Only two students wrote that social and cultural values decide what scientists should be doing. They believed that the work of scientists is to solve the problems caused due to development that affect lives of people.

> "Yes, I think social and a cultural value decides what scientist should work on because as we have seen that due to development of world lots of harmful gases are produced and effects on ozone layer and now it shows that what scientists should do." (S # 085)

> "I think social and cultural values should decide what scientist should do. When we learn science they learn disease which affect our person and they work on social and culture." (S # 041)

To sum up, majority of the students held naïve views in the social and cultural embeddedness aspect of NOS. Many students noted that science is independent from the social and cultural values. They were with the view that scientific knowledge and research deals scientific truth and the work of scientists is excavating truth.

Creativity and Imagination

Only about 29.8 % of the students held informed views in this aspect. Majority of the students (62.2 %) held transitional views and 29.8% of the students held informed views as per the analysis of the Likert part. When individual subscales were analyzed, 79.4% believed that scientist use their creativity and imagination when they collect data. 71.2% believed that scientists use their creativity and imagination when they analyze and interpret data. Interestingly, 56% (see appendix D) disagree with the statement "scientist does not use their imagination and creativity" because these conflict with their rational reasoning. Coming to the open-ended response, only 9.2% held informed views, the majority held transitional views. According to the rubric, the informed views required responses that indicated scientists use creativity and imagination throughout their work or in all phases of scientific investigation and experiment. For example, while designing, collecting data analyzing data. However, the majority of these students saw the role of creativity and imagination in the proliferation of new discoveries and invention. Moreover, many students gave example from the history of science which they might have learnt from the texts books or heard from their teachers. For instance, some of the students' responses are mentioned below:

> "Scientists use creativity and imagination during investigation during investigation and experimentations because to prove laws or theories creativity that it was true. For example, when sir Newton [sat] under an apple tree, apple fell down from the tree and he [analyzed] why an apple has fallen down. He [used] his creativity to experiments based on the apple, finally he discovered that it is because of gravitational force." (S # 57)

> "I think scientists use imagination and creativity during investigation/ experimentation to create new things." (S # 013)

> "Yes, I think scientists use creativity and imagination during investigation/ experimentations because they have to discover many things and to make humans they have to discover many things and to make human and to make unique and special one." (S # 041)

At the outset, majority of the students failed to recognize that creativity is involved in scientific investigation in the open-ended response although majority of the students stated that scientists use creativity and imagination when they collect data in the individual sub-scale of Likert items. On the other hand, there were some students with the naïve views who believed that scientists do not use creativity and imagination since creativity and imagination interfere in arriving at accurate answer and sometimes it would give rise to more problems.

> "No, because if scientists use creativity and imagination there will not be an exact answer, that is why they do not use imagination and creativity." (S # 81)

“I don’t think scientists use their imagination and creativity because they may find clashes with the ideas and the result of their experiments. Scientists think logically and critically.” (S # 039)

“No, because if they imagine any evidence it may turn out to be harmful to people.” (S# 051)

On the whole, majority of the students believed that scientists used creativity and imagination especially to make product of science and experiment attractive but failed to understand use of creativity and imagination in the scientific inquiry process.

Scientific Methods

Only 4.9 % of the students held informed views, 93.6% held transitional views and 1.5% held naïve views in Likert part. Coming to the individual Likert-items, it was over whelming to see 94.1% (see appendix D) of the students believed that scientist use different types of methods to conduct scientific investigation. Other interesting responses noted were that majority of the students (70.7 %) believed that “when scientist uses the scientific methods correctly, the result is often true and accurate.” In the open-ended the only minority (about 6.1 %) of the students held informed views, 35.1% held naïve views, and 42.9% held transitional views. The percentage of students, who held naïve views from the Likert scale and the open-ended responses, was inconsistent. In the open-ended response there were more students in the naive categories than the Likert scale. Students who were in transitional category in the open-ended questions noted that scientists used different methods during the investigation, but did not deeply understand what were the different type of methods scientists used. Some of the common responses of the students were:

Scientists use different types of methods or use different types of method because they should now what they are doing and what they are searching for accurate answer that they should have different methods.” (S#016)

While some students understood that scientists used different types of methods especially when one method fails then another method is used to get accurate conclusion. Students did not mention different types of methods that scientists would use during the scientific investigation.

> "Scientist follows a different type of method because if one method fails to give them the accurate result, they switch on to different or another method which would give correct and accurate result at last. Many scientists used different methods to prove that water is compound not an element." (S#052)

> "Scientist use different types of methods as if one fails other can do and to prove to others." (S #060)

On the other hand, in the open-ended response, the students are with naïve views and they believed that scientists use universal scientific methods to discover and to get accurate answer. For instance, some students wrote:

> "Scientist follows universal scientific method because discoveries should be applicable to all Scientists follow the universal method because to prove the method was correct and their results are true and accurate. For example, Newton law follow methods step by step such as the problem → gather information →form a hypothesis →make relevant observations →test hypothesis →form conclusions → results." (S#061)

> "Scientists follow universal scientific methods because I think every discovery, invention, law, and many more requires/ needs to go through many steps. They cannot be just developed randomly, they should go through many steps and then only people can accept them." (S#39)

On the whole, only minority of the students held informed views in this aspect though majority of the students noted that scientists use different methods during the investigation however, students do not deeply understand what they are.

Empirical Nature of Scientific Knowledge

Majority of the students (90%) held transitional views, 8% held naïve views and 2% held informed views as per the analysis of students' responses from the Likert-type items. In the sub-scale items 75.1% of the students agreed on the statement "scientists make sufficient observations and measurements to reduce errors and obtain reliable evidence". Similarly, 78.7% of the students believed the statement "Among different scientific theories, the acceptance of scientific theory depends on experimental evidence". In the open-ended response students were asked. "What in your view is science? What makes science different from other disciplines of inquiry? Majority (about 75.5%) of the students held transitional views, many of these students perceived science as the products of science knowledge and science exits around. Interestingly, many of these students noted the knowledge related to biology discipline. Some of the responses are mentioned as follow:

> "Science from my opinion science is studying of facts of our life. Science is different from other disciplines of inquiry." (S#020)

> "In my point of view, science is different from other discipline of inquiry. It is study of living thing and non-living things and it will be also about different type of diseases." S#042)

> "Science is different because in science we learn all the things that have live in earth and all the topics and present in science." (S#041)

> "The science is an environment study both living and non-living. The science is different from other discipline because science study is developed only after observable experiment but culture is developing only after past life." (S#022)

> "Science is different because it talks about the life on earth with the environment. Also the discoveries made to develop our world." (S#087)

On the other hand, there were student who believed that science is concerned with facts and while others believed that science is all about truth which has been proved. Students failed to see scientific knowledge is based on empirical evidence supported by observation and inference.

> “I think science is everything that we see around. Science is different because religion and philosophy all beliefs and science is all about truth proven by great people.” (S#050)

> “Science from my opinion science is studying of facts of our life. Science is different from other disciplines of inquiry.” (S#020)

On the whole, a majority held transitional views. These students failed to see science as empirical study of the natural phenomena from which scientific knowledge is generated, and science demands empirical evidence, observation and inference which makes it different from other disciplines.

Summary

In general, both qualitative and quantitative data showed that the majority of the students held naïve views in scientific theories and laws, social and cultural embeddedness and tentativeness aspects of NOS. In other aspects such as observation and inference, empirical of nature of scientific knowledge, scientific methods, and creativity and imagination, a majority of the students held transitional views. On the whole, only a minority of the students held informed views in all the aspect of NOS as per the analysis of the phase 1 data.

Result from Phase 2

Development of students' views on NOS after the intervention

Based on the results from the phase 1, an intervention was developed to enhance grade nine students' understanding of NOS through explicit and reflective approach in two units, namely Matter and Its Composition and Gas Law. For all the seven lessons taught, lesson plans were developed that focused on two to three aspects of NOS in each activity. Prior to the intervention, questionnaire consisting Likert-type items and open-ended questions, semi-structured interviews were administered to find out the preconception of NOS. After the intervention the same process were followed to see the impact of the intervention. In addition, class observation, students' journal and students' assignment were used as the data source in this phase. As mentioned earlier, this section answers "How does explicit and reflective approach influence grade nine Bhutanese students' views of NOS?"

Observation and Inference

From the pre-instruction questionnaire responses in the Likert part (Table 4.3) the majority (about 94.4%) of the students held transitional views in this aspect according to the scoring rubrics. Similarly, in the open-ended responses 83.3% of the students held transitional views. On the whole, only minority of the students held informed views both in the Likert part and the open-ended responses. Coming to the individual Likert sub-scales (Table from appendix C), interestingly the majority (about 83.3%), believed that scientists' observation of the same events may be different because the scientists use earlier experience and knowledge may affect their observations. The result indicated that the students are aware of the theory-laden aspect of NOS. Similarly, students who held transitional views believed that scientists' observation and interpretation are different because different scientists' have different thinking and ideas only and but did not emphasize on the scientists' prior knowledge and the background knowledge. For instance, some of the students' responses are in the next page.

"I think Scientists' observation and interpretation are different because scientists have their own ideas and inventions and some of their ideas could be same and it will be the greatest view on that part." (S # 09 pre-instruction questionnaire)

"I think scientists' observation and interpretation are different because all scientists don't think in the same way. Example if a scientist is making new compound to make that compound one may think of mixing all elements or one may think of making with one element so therefore the scientists' Observation and interpretation are different."(S#06) pre-instruction questionnaire)

"Scientists' observation and interpretation are different because their thinking will be not same .There thinking are different so similarly they have different ideas and thoughts." (S #08 pre- instruction questionnaire)

"I think scientists' observation and interpretation are different because all scientists don't think is same way. Example if a scientist is making new compound to make that compound one may think of mixing all elements or one may think of making with one element so therefore the scientist's observation and interpretation are different." (S#06 pre-instruction questionnaire)

Prior to intervention, the majority of the students held transitional views and after the intervention there was substantial development in students' understanding of NOS in this aspect. The students with naïve views had developed either into transitional or informed views and transitional to informed views. There were two lessons that had explicitly discussed observation and inference aspect of NOS as mentioned earlier in Table 3.4

Table 4.3 Number (n=18) and percentage of Likert scale responses from the pre-instruction and post-instruction questionnaire of phase 2 holding naïve, transitional and informed views in aspects of NOS.

	Likert-Type items						Open-ended							
	Pre-instruction			Post instruction			Pre-instruction Questionnaire				Post-instruction Questionnaire			
NOS aspects	**N**	**T**	**I**	**N**	**T**	**I**	**N/C**	**N**	**T**	**I**	**N/C**	**N**	**T**	**I**
Observation and inference	0 (0)	17 (94.6)	1 (5.3)	0 (0)	6 (33.3)	12 (66.7)	0 (0)	0 (0)	15 (83.3)	3 (16.7)	0 (0)	0 (0)	6 (33.3)	12 (66.7)
Tentativeness of scientific knowledge	5 (26.3)	10 (52.6)	3 (15.8)	0 (0)	9 (50)	9 (50)	1 (5.6)	12 (66.7)	5 (27.8)	0 (0)	0 (0)	0 (0)	10 (55.6)	8 (44.4)
Scientific theories and laws	9 (50)	9 (50)	0 (0)	1 (5.6)	9 (50)	8 (44.4)	1uu (5.6)	17 (94.4)	0 (0)	0 (0)	0 (0)	1 (5.6)	7 (38.9)	10 (55.6)
Social and cultural influence on science	8 (44.4)	10 (55.6)	0 (0)	0 (0)	10 (55.6)	8 (44.4)	2 (11.1)	16 (88.9)	0 (0)	0 (0)	0 (0)	2 (11.1)	11 (61.1)	5 (27.8)
Imagination and creativity	1 (5.6)	9 (50)	8 (44.4)	0 (0)	2 (11.1)	16 (88.9)	0 (0)	2 (11.1)	16 (88.9)	0 (0)	1 (5.6)	0 (0)	5 (27.8)	12 (66.7)
Methods of scientific investigation	1 (5.6)	17 (94.4)	0 (0)	0 (0)	10 (55.6)	8 (44.4)	0 (0)	2 (11.1)	15 (83.3)	1 (5.6)	0 (0)	1 (5.6)	10 (55.6)	7 (38.9)
The empirical nature of scientific knowledge	1 (5.6)	17 (94.4)	0 (0)	1 (5.6)	6 (33.3)	11 (61.1)	0 (0)	6 (33.3)	11 (61.1)	1 (5.6	0 (0)	1 (5.6)	5 (27.8)	12 (66.7)

Note : N= Naïve, T= Transitional, I= Informed, N/C=Non-classifiable

To develop students' views on observation and inference from naïve to informed, a decontextualized activity (mystery box activity) was used to teach the lesson after studying the composition of matter according to different philosophers and scientists. The students' prior knowledge on what science is? In the beginning, most of the students said "Science learning is all about truth and everything in science is true." Similarly, when the teacher assessed students' prior knowledge on observation and inference, the students' responses showed that the majority of the students held transitional views, as they said, "Observation means estimating, thinking, feeling, concentrating, and imagining."

On probing students' prior knowledge on inference, surprisingly silence was felt in the classroom. On further probing, one of the students said "interference" which showed that students held some misconception which is basically because of the language, where the students misinterpret it. To clarify students' misconception the teacher picked up the black calculator box from one of the students' desk and asked the student what you observe. Student responded, "Black cello tape, smooth surface, hard, rectangular in shape." Teacher asked what you think could be inside the box as per your observation, the student said, "There is geometry box and some other said there is calculator inside the box." Teacher further asked, "What made you think so? Students said, "Because of the shape of the box we imagined and we have some experience about it." Then the teacher further explained about the term inference which means drawing logical conclusion from the observation.

Once the students had some concept of observation and inference, the teacher introduced a decontextualized activity (mystery box) to make the students realize that in science observation does not simply refers to seeing, instead all five sense collect information about the natural phenomena. Mystery box was prepared from cardboard paper and materials such as pebbles; chalk, sticks, wood pieces and cotton ball. All the materials were placed inside the box and glued. All the groups were provided with a mystery box each and were asked to make observations of what is there inside the box, like a scientist. In this activity, teacher encouraged the students to work like scientists in group of four members and infer the shape of an object inside the mystery box without opening the box. The students were provided with magnet and stethoscope along with some question to guide them during the investigation. The questions like (1) what is the shape of an object inside the mystery box? (2) What object could be inside? (3) Draw the possible shape of the object that is hidden inside? After completing the investigation, students presented their findings to the whole class. One of the groups, for example, concluded that the shape of the object inside the mystery box could be cylindrical as per their close observation. Their observation and inferences are mentioned below:

Table 4.4 Example of observation and inference during mystery box activity.

Observation	Inference
1. Magnet did not attract any object.	1. We think the object inside is not metal.
2. When we sake the box we can hear a rolling sound produced.	2. We think there are pebbles are there inside the box.
3. When we lift it is light.	3 We think the object inside is pebble.

Towards the end of lesson teacher led a reflective conversation with the students to help them understand and differentiate between observation and inference in science. Some of the conversation between teacher and students during the explicit discussion are mentioned below:

T: What can you conclude after doing this activity about what can you say about what is science?

S: Science demands many evidence.

T: Science demands empirical evidence, so we need observation and inference to conclude.

T: Why do you think that different groups have different inference?

S: Because they have their own views.

T: What else?

T: What effects the interpretation? What do you use?

S: Prior knowledge, we use senses.

T: Everyone uses senses and you look at the same object but why is your interpretation different.

S: Because of different thinking.

T: And another one is.

S: Different observation.

T: And then what else?

S: Different ideas.

T: Did anyone have the past experience?

S: Yes (chorus).

T: Can you see the object inside?

S: No.

T: How were you able to infer the shape of the mystery object?

S: Listening to the sound.

S: Through observation, and imagining.

S: Using creativity, past experience.

T: Did you make direct observation?

S: No, madam.

T: Like what?

S: Eyes, ears.

T: What is inference?

S: Thinking and drawing conclusion.

First assignments and the journals on observation and inference indicated that the majority of the students were not able to define the term observation and inference after the first lesson. In the journal entries, many students wrote that they were not clear about observation and inference. Only few students could differentiate the terms. For instance, one of the students (S # 06) in his assignment wrote:

> "Observation means the act of watching somebody/something carefully for e.g. when we are conducting an experiment we need to make careful observation. Inference is to form an opinion or conclusion about the experiment that we conduct."

In the fourth lesson, while learning ‘Phases of States of Matter’ observation and inference aspect of NOS were explicitly discussed. This lesson was adopted and adapted from (Cornett *et al*. n.d). Prior to the teaching, the teacher arranged seven stations that showed different phenomenon like: melting, evaporation, sublimation, condensation, freezing and vaporization. Students rotated between stations to investigate the phase changes in each station. During this activity students were encouraged to observe and inferred the natural phenomenon that occurred in each station. In addition, students were also asked to determine the substance that was absorbing or releasing heat? Students spend about 5 minutes per station to record their observations

Station 1: Coconut oil (melting), place watch glass on warm hotplate, containers of coconut oil with Popsicle stick for placing on watch glass.

Station 2: (Condensation) Watch glass on beaker of water on hotplate

Station 3: Evaporating alcohols in hand (vaporization) drop few drops of alcohol on your palm

Station: 4 Takes two spatula of Ammonium chloride in a test tube and heat it. Observe what happens. (Sublimation)

Station: 5 Cooling wax (freezing) lit candle with popsicle stick and paper for placing wax

Station6: Boiling water on hotplate (vaporization)

Station 7: Cold can of soda (condensation)

Once the students completed their observation, explicit and reflective discussions were carried out. In the discussion, students were asked to reflect what have they observed and inferred in each phase changes that took places in each station. It was seen that some students developed views unlike the previous lesson. Conversation and responses with some of the students during the explicit and reflective discussion are mentioned below:

T: What did you observe on station 2 when watch glass is place on beaker of water on hotplate?

S: Water is boiling.

S: I observed there were tiny droplets of water on the surface of watch glass.

S: Water vapor is rising up.

T: What happen to the water vapor? What happen to the surface of the glass?

S: Small droplets are formed in the surface of the glass.

T: What can you infer?

S: Condensation is taking place.

T: How do you know?

S: We use our prior knowledge to infer that is condensation and we also been similar things.

T: What is observation?

S: Observation means we use our physical senses to observe.

T: What is inference?

S: Inference is trying to make conclusion using prior knowledge.

T: So how your work is similar to what scientists work?

S: We use prior knowledge, made prediction, and observation, have hypothesis, infer, and communicate.

In the post-instruction questionnaire, students were asked, "Do you think all scientists' observation and interpretations are same or different? With example, explain why you think scientists' observations and interpretations are same or different." From the responses to this question, a substantial development of students' views in this aspect was noted in open-ended responses. The percentage of students who held informed view changed from 9.7% to 66.7%. The students with the informed views noted that scientists' observation and inference are different because of the different thinking, prior knowledge and the scientists' background that showed the theory-laden aspect of the NOS. Some of the students' responses in this regard are as mentioned below:

"As we know that according to their main ideas and logic or knowledge they have different observation and they will have their own evidences to explain their experiment. They will have different knowledge, different prior knowledge and different background to support." (S#012 post-instruction questionnaire)

"No, because they have own knowledge, idea interpretation based on their own thinking and prior knowledge and on the experiment they have been doing. For example, like when we are doing our experiment on syringe the, we got different observation because of our different imagination and feeling which indicates that scientist were also like us having different imagination and feelings and ideas on their experimentation or unknown things. So it is clearly tells us that they have different observations and interpretation." (S # 13, post-instruction questionnaire)

"Scientists' observation and interpretation are different because scientists have different views and observation, ideas while investigating their investigation. For example, while we were doing our experiment on the mystery box though the object inside the mystery box was same though we came up with different ideas, views and our inference and observation were different. So, hence forth with our experiments we also know that scientists' will be having different observation and interpretation like us."(S #014, post-instruction questionnaire)

Prior to intervention only 16.7% of the students held informed views however, after the intervention a majority, (about 66.7%) held informed views in the open-ended responses. On the whole, there was development in students' views in observation and inference aspect of NOS to certain extent after the intervention

Tentativeness of Scientific Knowledge

Altogether, 15.8% of the students held informed views in this aspect of NOS in the pre-instructions response of the Likert part but in the open-ended responses, interestingly, none of the students held informed views. Coming to individual subscale, only 38.9% of the students believed that scientific theories are subject to on-going testing and revision. 27.8% of the students believed that, “a new interpretation of data can change our present scientific knowledge”. About 44.4% of the students believed that “scientific theories based on accurate experimentation will not be changed.” The open-ended responses indicated that the majority of the student held naïve views. Many of the students who held naïve views, believed that scientific knowledge/scientific theories are not going to change because scientific theories or knowledge are strongly proven with many facts. Some of the students’ responses are mentioned below:

> “Scientific theory has not changed since it has been already prepared early in the past and proved.” (S # 014 pre-instruction questionnaire)

> “Scientific theory and scientific knowledge is not going to change because it has been established from the past and have been proved after much experimentation.” (S # 014 pre-interview)

> “After scientists develop a scientific theory never change because it was already proof with strong evidence and facts. Example cell theory.” (S # 017 pre-instruction questionnaire)

> “No, scientific theory does not change as theory are made from strong observation and it has been proven with strong facts and it has been followed from many years and even now we are learning that same theory that they have proven.” (S # 018 pre-instruction questionnaire)

To develop students’ views on tentativeness aspect of NOS, two topics were explicitly designed to draw students’ attention in tentative aspect of NOS. It was planned to teach in the topics Matter and its Composition and Law of Conservation of Mass. In the first topic mentioned above, the students learnt about the time line of different philosophers and scientists ideas of composition of matters of and how the knowledge of the composition of matter had changed over the past. Accordingly, the teacher divided the students into four groups of five. Each group were to pick up one of the names of the philosophers or the scientists and then read the history about the origin of their ideas about the composition of matter and discuss about that particular philosopher's or scientists' ideas. The materials were taken from sources like internet, Wikipedia, and text books. The groups were also asked to prepare a summary chart and then report to rest of the class. After the presentation, students were to trace out the changes in the ideas of composition. At the end of the presentation, teacher led explicit and reflective discussions that enabled students to reflect the tentativeness aspects of NOS from the lesson. Some of the conversation that took place during the discussions are mentioned below:

T: What did philosopher like Epodolecles thought about composition of matter in the early days?"

S: Matter was made up of four elements such as earth, fire, water and air.

T: How was it Epodolecles idea of composition of matter was different from Democritus?

S: Democritus believed that atoms could not be created, destroyed, or further divided. He believed that matter was made up of tiny individual particles called atomoi. Epodolecles ideas are matter is made from fire, earth, water and air.

T: Was Democritus' ideas about the composition of matter accepted?

S: No.

T: Who rejected Democritus' ideas about the composition of matter and why?

S: Aristotle rejected Democritus ideas about the composition of matter as he could not answer the question of Aristotle and there were no evidence to show about his ideas.

T: Actually whose ideas were correct?

S: Democritus (chorus).

T: After many years who revived Democritus ideas and how?

S: John Dalton revived Democritus ideas and experimented.

T: Do you scientific knowledge and theory is going to change over a time? How?

S: Yes, it is going to change with the new evidence.

T: Do you think ideas are durable?

T: Yes.

T: Why was John Dalton accepted? / What did he do? / How did he come up?

S: John Dalton revised Democritus ideas through experimentation and had empirical evidence to show.

T: What do you need in science?

S: Science needs lots of evidences.

Through explicit and reflective discussion, it was observed that students could understand that scientific knowledge would change with the availability of the new evidence. Students' responses during teacher and students conversation showed that some students could understand tentative aspect of NOS.

In the second lesson, tentative aspect of NOS was explicitly discussed after students presented the shape of an object inside the mystery box as mention earlier in the inference and observation development of students' understanding of NOS. Therefore, before beginning the activity the following questions were asked to the students: (1) If you were a scientist how are you going to make an observation of what is there inside the box? (2) What are the materials that you would use? After the presentation on the mystery shape, the tentative aspects of NOS were explicitly discussed. Students were encouraged to make connection between inquiry activities and the aspects of NOS through question answer session. Some of the conversations between teacher and students during the explicit and reflective discussion are mentioned below:

T: How were you able to infer the shape of the mystery object?

S: Listening to the sound that was making to observation, imagining, use creativity, past experience.

T: Did you make direct observation?

S: No, madam.

T: If you were given some instruments such as X-ray to see what was in the mystery box do you think you're your ideas are going to change? Why?

S: Yes, because technologies can help us to see thing inside.

T: So you mean scientific knowledge is going to change.

S: Yes.

T: How is the process you have used to infer the shape of the mystery object is similar to the work of scientist/ physicists used to construct models of the atom?

S: We made indirect observation and scientist also make indirect observation.

T: Did you make the direct observation.

S: No.

T: Do you make the indirect observation, what else?

S: We used past knowledge and they also use the prior knowledge.

T: Do you think reinterpretation of the data will change the scientific theory and scientific knowledge?

S: Yes.

T: What else?

S: They used instrument and we also used instrument like stethoscope to listen to the sound.

As mentioned earlier, prior to intervention, none of the students held informed views in the open ended responses though 15.8% of the students held informed views in the Likert-types items. One of the students (S # 014) in the pre-interview said "Scientific theory and scientific knowledge is not going to change because it has been proven and established from the past after much experimentation." However, after the intervention, majority of the student held informed views both in the Likert-type items and open-ended responses.

A total of 66.7% of the students held informed views at the end of the intervention. Students were with a view that scientific theory will change because of the new evidence, advancement in the technology and new interpretation of data. However, not so many students realized that the reinterpretation could lead to tentativeness of scientific theory or scientific knowledge. For example, when some of the students responded as mentioned below:

> "Scientific theory may change with new evidences and reinterpretation while conducting experiment. For example John Dalton proved all matter cannot be created nor be destroyed." (S # 014 post-instruction questionnaire)

> "After scientists develop a scientific theory does change with new evidence and proofs as a new interpretation of data can change our present scientific knowledge and also it may be completely replaced by new theories when new evidence is found. Composition of matter which is idea of Democritus is change by Aristotle it was further changed by new evidence by John Dalton." (S# 017 post-instruction questionnaire)

> "Yes, scientific theories will change with new evidence found in advanced technologies e.g. the cell theory also went many changes with the collection of many evidences and numerous experiments and new interpretation. Atomic theory also went on many changes." (S # 03 post- instruction questionnaires)

The development of students understanding of NOS in this aspect seemed to be considerably high as compared to other aspects in the pre-questionnaire. On examination of individual Likert items responses, only 38.9% of the students believed that "Scientific theories are subject to on-going testing and revision" prior to the intervention but after the intervention, it changed to 88.9%. Similarly, 44.4% of students in the individual Likert-type items disagreed that scientific theories based on accurate experimentation will not be changed prior to the intervention and after the intervention 66.7 % of the students disagreed this statement.

The development in students' understanding of tentative aspect of NOS was observed at the end of the intervention. Prior to the intervention, majority of the students held naïve views. They believed that a scientific theory is not going to change because it has been proven with many facts. However, the explicit and reflective discussion in the second time helped the students to develop informed views on the scientific theory which is subject to change. The students seemed to realize that the scientific knowledge would change due to reinterpretation and advancement in the technology.

Scientific Theories and Scientific Laws

Prior to the intervention, none of the students held informed views in scientific theories and scientific laws both in Likert and open-ended responses. Coming to the individual subscale of Likert-types items, the majority of the students (77.8%) believed that "Scientific laws are theories that have been proven" in the sub-scale response in the Likert items type. The 77.7 % of the students believed that "The scientific theory will change but the scientific law will not change." Similarly, in the open-ended responses some students viewed that students believed that scientific laws are the scientific theories that have been proven. Some responses of the students are:

"Yes, scientific theories and laws are different as the law are derived from scientific theories which are reliable and have been proved through evidences and researches made earlier. E.g the theory of gas helped and supported to derive the gas laws. Boyle's law, Charles law from kinetic theory of gas." (S # 03 pre-questionnaire)

"No, there is no difference between a scientific theory and scientific law because from scientific theory the scientific laws have been made." (S # 016 pre-questionnaire)

In the open-ended responses, interestingly, some students viewed scientific laws as a rule that a scientist would follow during scientific research. For example, some of the students' responses are stated below:

> “Yes there is little difference between the both scientific theory and scientific law. Scientific theory means the study of idea and scientific law certain rules that scientist have to follow in order to get the result or idea examples Boyles laws, Pascal law, cell theory, atomic theory, etc.” (S # 013 pre-questionnaire)

> “Yes, there is difference, because scientific theory is the theory about the scientific research or things and a scientific law refers to the law that is used when scientists do the research about some things. It can be the law about scientific research and facts.” (S # 010 (pre-questionnaire)

On further interviewing, students said, “Scientific theories can be used for conducting experiments and conducting observations and framing scientific laws, and these are the rules scientists exactly use or follow when they do research.” (S # 010 pre-interview)

To develop students’ views on scientific theories and scientific laws aspect of NOS, a guided inquiry teaching approach was used to teach Law of Conservation of Mass, Boyles Law and Charles Law. While teaching law of conservation of mass teacher began the lesson with a demonstration of chemical reaction in closed system and open system heating copper carbonate. Before the demonstration the students were asked to predict the mass of reactants and the mass of products before and after the reaction. All the students predicted that the mass in a closed system and in the open system would decrease after the reaction. After the demonstration, students were challenged to answer, “Does the mass of the reactant and the product difference in chemical reaction changes in a closed system?” To save the time, students were provided with the materials like vinegar, baking soda, electrical, balloon, string and measuring cylinder and a balance. Students were constantly guided to develop their procedure. Having designed their procedures, all the groups came together to discuss on their procedure. The teacher meanwhile ensured safety about their procedure. During the experimentation, students were asked to record the weight before the reaction and after the reaction. Students were also reminded not to fake their data, and the importance of being honest in reporting their data. After the students have developed a procedure, the entire student came for a whole class discussion to compare and contrast the procedure. Here at this point, importance of collaboration and sharing of the scientists' ideas and work were discussed and this also reflected how scientists work. When student were conducting experiment teacher went around and posed question whenever the student got stuck, to keep them on track and scaffold their thinking. For example, (1) what are you trying to learn from this experiment? (2) Why do you choose this particular method?"

During the experimentation when looked around the class, the students were very much absorbed in the activity and were trying to get as many data as possible. In the process of experimentation students learnt organizational skills that are required in the scientific investigation such as organizing procedure, making observation, managing data table and drawing conclusion. Furthermore, it improved students writing skills and team work. In the sharing session the student were encouraged to present hypothesis, encouraged to discuss, and critique other groups' works. During the explicit and reflective discussion towards the end of the lesson, students were asked to define Law of Conservation of Mass and then followed by questions like "What does a scientific law mean?" Majority of the students said, "Scientific law is a rule that scientists follow while other said, "It is a universal step to explain the experiment." Though the answers varied, the majority of the students viewed scientific law as the "rules" followed by scientists during the scientific investigation. The teacher let the students to reflect back on law of conservation of mass and asked whether it was a rule the scientist follow. The teacher further asked the students to look at the relationship between the mass of the reactant and the product before the reaction and after the reaction and then define scientific law again. Some of the conversation that took place during the explicit and reflective discussions are mentioned below:

T: What does scientific law means?

S: It is the universal step to explain the experiment.

T: You mean to say that it is the universal step to explain the experiment. Anyone would like to add.

T: What is scientific law means?

S: It is the rule that is followed by the scientists

S: Step by step method.

T: What do you understand by scientific laws?

S: (No answer)

S: A scientific law in science mainly states that we cannot the same law the step by step method to experiment.

T: You mean to say that law is kind of the rule, so you will not follow the same rule in the investigation. Ok, who would like to try it again?

S: It is a rule.

T: That means you all agree scientific law is the rule that scientists follow.

S: Yes madam (chorus)

T: Who doesn't agree?

T: Can you see the relationship between the product and the mass?

S: Yes.

T: What does scientific law means now?

S: It shows the relationship.

T: Do you think scientific law is going to change?

S: No.

T: Look at laws of conservation and law of conservation of energy. They have been modified now when Albert Einstein came up with $E=mc^2$, so whole thing has been modified then we have law of conservation of mass and energy.

Figure 4.2 Student engaged in law of conservation of mass experiment

Another lesson in which scientific laws and scientific theories were explicitly discussed was during the teaching-learning of Boyle's Law. The lesson was taught using guided inquiry approach. The teacher began the lesson with a video clip to show and explain Kinetic Theory of Gas, which allowed the students to visualize the motion of gas molecules. Then the students were asked to connect what they had learnt from the video clip to the pressure and the volume relationship followed by letting students to write the postulate of kinetic theory of gas on the board. After students understood the kinetic molecular theory, the teacher asked the students what scientific theory meant. Some of the students said, "Scientific theory means explanation of the behavior." Further, the teacher explicitly explained again the meaning of scientific theory with an example of kinetic molecular theory of gas.

Next the teacher engaged students in a demonstration to probe prior their knowledge. In this activity, the students were asked to predict the size of balloon inserted inside an air tight syringe when the plunger is pushed. The students were let to think and design an investigation to see 'how pressure is related to the volume'.

Students started to work on their investigation which kept them mentally engaged to find out the relationship between the volume and the pressure. At first the student developed a hypothesis and then developed a procedure to test their hypothesis as shown below:

1. Take a syringe.
2. Make the syringe air tight.
3. Fill the syringe with air by pulling out the plunger.
4. Hold the syringe in a clamp.
5. After the syringe is filled with air, try to compress the air with the load like book, or stone etc.by placing our it on the plunger.
6. At first put one book on top of the plunger and record the volume of air inside the syringe that has been compressed.
7. Repeat the steps.

After the investigation, students interpreted their data in graphical representation to show the relationship between volumes and pressure and presented to the whole class. Students were encouraged to define Boyle’s law by looking at the relationship between pressure and volume. Then the teacher introduced a mathematical equation that described the relationship between pressure and volume. Once students were clear about the mathematical equations then students were taught to solve the numerical. Towards the end, the students were engaged in explicit and reflective discussion in distinguishing scientific theories and scientific laws. Some of the conservation between teacher and students that took place there are presented below:

T: What is scientific law?

S: Scientific laws describe the relationship between two variables.

S: Scientific laws are expressed in mathematical equation.

T: Do you think scientific laws and scientific theories are same?

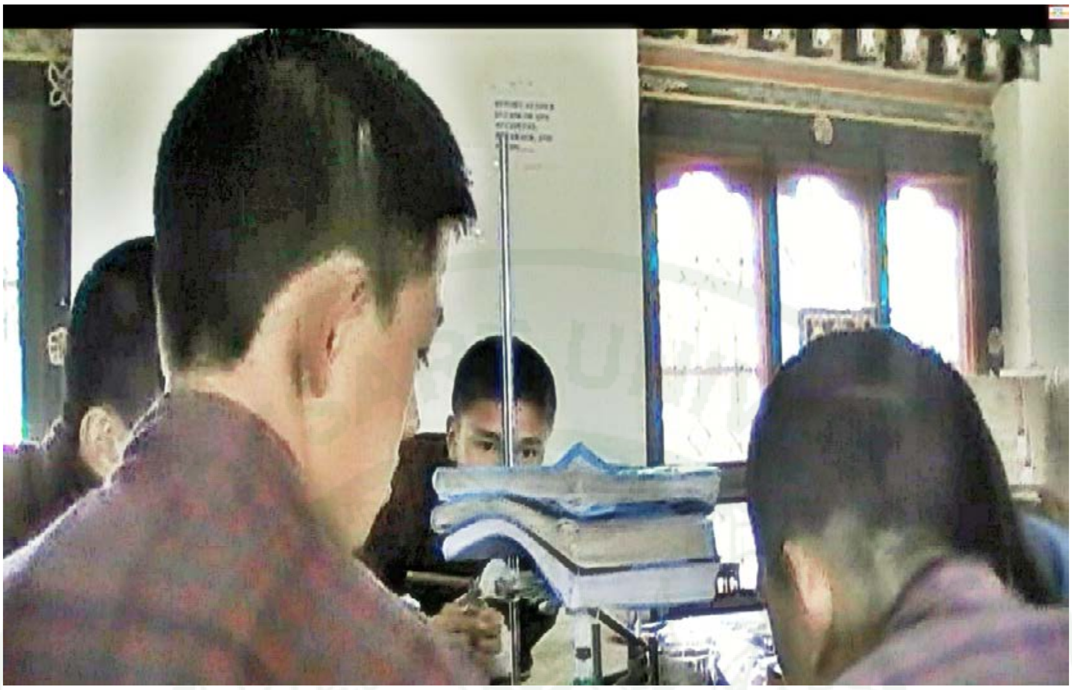

Figure 4.3 Students engaged in investigating relationship between volume and pressure.

S: They are different.

T: How are they different from one another?

S: A scientific law describes the relationship and scientific theories.

T: Are scientific laws are theories that has been proven?

S: No.

T: Do you think scientific laws and theory change?

S: Yes. (About half of the students)

By the end of the lesson many students were able to distinguish between scientific laws and scientific theory on the basis of its function. Students seemed to have developed their understanding on scientific law and scientific theory as compared to the previous lesson from the law of conservation of mass.

The 7th lesson on Charles' law was taught through guided inquiry. Distinction between scientific law and theory was explicitly discussed towards the end of the lesson. Teacher demonstrated an activity with balloon on the neck of an empty bottle and immersed in hot and cold water. Before beginning the demonstration, the teacher let the students predict size of the balloon when placed first in hot water and secondly in cold water. Students were challenged to determine the relationship between the volume and temperature. Each group designed an experiment to investigate the relationship between volume and temperature and worked on their experiments using the material provided and based on the question provided to them. Group 1 tried using the balloon on top of the bottle and placing it in the hot water bath. The circumference of the balloon was measured and temperature was recorded when some ice cubes was added to the water bath to reduce the temperature. Another group conducted their experimentation by placing the bottle with a balloon in the cold water and measured the circumference of the balloon and then gradually heated the water. The circumference of the balloon was measured at different temperatures at different interval while other two groups dipped air tight syringe in water hot, warm and ice water and recorded the temperatures and volume of an air syringe. After the experimentation students reported their results in the graphic representation to the whole class. Then the teacher explicitly draws students' attention on distinction between scientific laws and scientific theories. In the third lesson the students seemed to answer questions more confidently than the in previous two lessons. Some of the conservation between students and teacher during the explicit discussion are mentioned below:

T: What do you understand by scientific law?

S: Scientific laws are study of natural phenomena or the relationship of natural phenomena. (S # 02)

S: Scientific laws are description of a natural and also expressed by mathematical equation. (S # 013)

S: A scientific law is study of natural relationship of phenomena. Scientific laws offer description of what happens, but not explanation for how it happens? (S # 011)

T: What is scientific theory? Let's us look at the kinetic theory. What does kinetic molecular theory of gas talks about?

S: It talks about the behavior of the molecules.

T: Does it talk about the relationship?

S: No.

T: What does it talk about it?

S: It explains the behavior of the molecules/ movement of the gas molecules

S: Explanation part is the theory and relationship is the law.

T: Do you think scientific law is going to change?

S: Yes (chorus).

T: And what about theory?

S: Scientific theory will change (chorus).

After the intervention, the students' responses from the post-instruction questionnaire indicated that about 44.4% of the students held informed views in the Likert scale and 55.6% of the students held transitional view in the open-ended responses. Those students who held informed views were able to differentiate scientific laws from scientific theories on the basis of its function. These students expressed that scientific theories are the explanation of the phenomenon while scientific law describes the relationships between such phenomena.

> "Yes, scientific laws and scientific theories are completely two different things, scientific laws are the relation between the natural world of science and deals with what part, whereas scientific theories demands on more explanation and deals with how it works and how it is appropriate e.g. the theory of kinetic molecular theory explains the different states of molecules whereas the Charles law dealing on the gas law relates the relationship between volume and temperature. Theory: explanation (movements of molecules). Laws: relation Charles law (between pressure and temperature)." (S # 03 post-questionnaire)

> "Yes, there is difference between a scientific theory and scientific law because scientific theory means an explanation e.g. gas of the molecules so that we

cannot the experience and explanation and scientific law means the relationship between the volume and pressure.” (S # 08 post-questionnaire)

“Yes, there is difference between a scientific theory and scientific law because scientific laws tell about the relationship between natural phenomena and scientific theory is about the explanation. Boyle’s law which is at a constant temperature the volume is inversely proportional to pressure and theory kinetic theory of matter which talks about the exerting of pressure when the container is heated.” (S # 015 post-questionnaire)

In general, development in students’ views on scientific theories and scientific laws were observed in students at the end of the intervention. Interestingly, none of the students mentioned scientific laws rules that scientists follow during the investigation after the intervention.

Social and Cultural Embeddedness

The responses from both Likert scale and the open-ended pre-instruction questionnaire showed that none of the students held informed views of NOS. Interestingly, coming to individual subscale 77.4 % of the students believed “Scientific research is not influenced by society and culture because scientists are trained to conduct pure unbiased studies.” In another subscale 72.2% of the students believed “Science is not influenced by cultural and societal values because science is independent of society and culture.” Similarly, the open-ended responses also indicated that the majority (exactly 88.9 %) of the students held naïve views prior to the intervention. Some of these students viewed that scientific knowledge and research deals with scientific truth and it is not affected by culture and society. The work of scientists is to search for truth and science is based on fact and experiments whereas social and culture is something to do with the religion and beliefs. As a result students seemed to see science independent from the society and culture.

"Social and cultural values do not decide on science because since, science is independent and social and cultural cannot interrupt because science is accurate in terms of answer and knowledge. Example social and cultural believes in ghost where as in science they do not believe in ghost." (S#014pre-instruction questionnaire)

"No, the social and cultural values don't decide what scientists should work on because science has their own facts and experiment and observation which is true while in social it have different cultural and regions to be followed." (S # 015 pre-instruction questionnaire)

"Social and cultural values does not decide on science because science has the facts and its observation and experimental are true where as social and cultural values it may be wrong or not true. [For] example social and cultural values believe in ghost or rituals whereas science totally disagrees in ghost or rituals." (S # 018 pre-instruction questionnaire)

Prior to intervention, the majority of the students held naive views. In order to develop students' views in this aspect of NOS, only one lesson was developed due to the nature of content. A social and cultural embeddedness aspect of NOS was integrated in the topic Matter and Its Composition. While teaching ideas of composition of matter as mentioned earlier in this chapter, each group were given one philosophers' or scientists' idea about the composition of matter were to discuss. Students were encouraged to discuss questions like "How the knowledge of the composition of matter had changed from the past." "How did the social and cultural values influence the scientific knowledge?"

The groups were supposed to discuss Democritus ideas of composition of matter such as "How did he come up with idea of composition of matter?" "How did he revive Democritus' idea of composition of matter?" "What was the Reason for rejection of Democritus ideas of composition of matter?" For example, the important issues that was included in the time line of the Greek Philosopher Democritus (460-370 B.C.E.) are as below:

"The Greek philosopher Democritus (460-370 B.C.E.) was the first person to propose the idea that matter was not infinitely divisible. He believed matter was made up of tiny individual particles called *atomoi*, from which the English word atom is derived. Democritus believed that atoms could not be created, destroyed, or further divided. Democritus and a summary of his ideas are shown below.

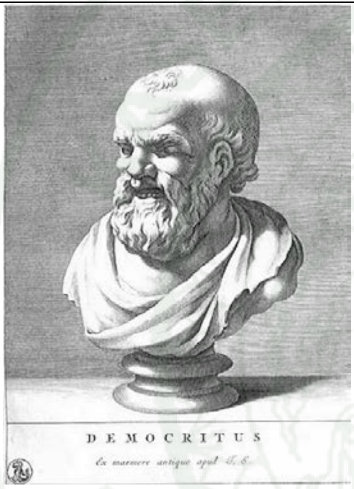	Democritus's ideas - World is composed of empty space through which atoms move. - Atoms are solid, homogeneous, indestructible, and indivisible. - Different kinds of atoms have different sizes and shapes - The differing properties of matter are due to the size, shape, and movement of atoms. - Apparent changes in matter result from changes in the groupings of atoms and not from changes in the atoms themselves.

Figure 4.5: Democritus's ideas on composition of matter

In fairness to Democritus, it was impossible for him or anyone else of his time to determine what held the atoms together. More than two thousand years would pass before the answer was known. However, it is important to realize that Democritus's ideas were just the ideas and not science. Without the benefit of being able to conduct controlled experiments, Democritus could not test to see if his ideas were valid. The idea of the atom was strongly opposed by Aristotle and others. Because of this, the atom receded into the background. Although there is a fairly continuous pattern of atomistic thought through the ages, only a relative few scholars gave it much thought. Due to complex circumstances beyond the scope of this lesson, the Catholic Church accepted Aristotle's position and came to equate atomistic ideas with Godlessness. For example, “Democritus of Abdera said that there is no end to the universe, since it was not created by any outside power.”

Unfortunately, for the advancement of science, Aristotle was able to gain wide acceptance for his own ideas on nature ideas that denied the existence of atoms. Incredibly, the influence of Aristotle was so great and the development of science so primitive that his denial of the existence of atoms went largely unchallenged for two thousand years! [To be fair to him, though, common sense told him with his eyes that atoms could not be seen] (Anonymous). After the presentation about the ideas of composition of matter according to different philosophers and scientists, social and cultural aspect of NOS was explicitly discussed. For instance, some example of the conservation that took place is discussed below:

T: Do you think social and cultural values plays important role in science?

S: Yes.

T: Who was actually correct?

S: Democritus.

T: To whom did the society believe more and why?

S: Society believes on more Aristotle as Aristotle was more popular in his time was the Catholic Church accepted Aristotle’s idea about the composition of matter.

At the outset, the students’ views in this aspect had developed from naïve to informed views though less substantially as compared to other aspects of NOS. Prior to the intervention, majority 94.4% of the students held naïve views. However, after the intervention, 61.1% held transitional views and 27.8% of the students’ held informed views in the open-ended response. Some of the students’ responses with informed views are mentioned below:

“Yes, social and cultural values decide what scientist should work on because if different scientists are working on something to support their experiment they have to show their evidence to the society and their society will accept or neglect. E.g. Democritus' atomic theory was not accepted by the society. Therefore, cultural and social values influence scientists work." (S # 02 post-instruction questionnaire)

"Yes, cultural values and social values decides what scientists should work on as when a scientist come up with the evidence that particular scientist have to show their full observation and inference and with evidence and if the scientists don't agree with the investigation the society will not accept." (S # 06 post-instruction questionnaire).

"Yes, Social and cultural values decides what scientist should work on as, social and cultural elements such as religion will support science and it will affect the science knowledge." (S # 018 post-instruction questionnaire)

In general, the development of students' understanding from naïve to informed views was very minimal, only 27.8% of the students changed their views from naïve to informed views after the intervention but to transitional views were seen more. The students who were categorized into informed views were able to write that a scientist's work is influenced by the society and cultural values and it determines what and how science is conducted and accepted.

Creativity and Imagination

Prior to intervention about 50% of the students held transitional views and 44.4% with informed views as indicated from the Likert scale in Table 4.1 When individual sub-scale were analyzed, more than 50% of the students disagreed on the statement "Scientists do not use their imagination and creativity because these conflict their rational reasoning." 61.1% disagree on the statement "Scientists do not use their imagination and creativity because these can interfere with the objectivity." In the open-ended response, the majority about 88.9% of the students held transitional views. The students who held transitional views saw that scientists use their creativity and imagination in the new discoveries and invention; moreover many students gave example from the history of science which they might have learnt from the texts books or heard from their teachers. In addition, the majority of the students failed to recognize that creativity is involved in the process of science in the open-ended response.

> "Yes, I think scientists use creativity and imagination during investigation/ experimentation because if scientists don't have creativity they can't discover many new things where scientific use their creativity and knowledge and invent many things." (S # 015 pre-instruction questionnaire)

> "Yes, I think Scientists use creativity and imagination during investigation/ experiment because if scientists are investigating about a bone from the ancient time they need to imagine at what period that bone was and to whom does it belong to." (S # 06 pre-instruction questionnaire)

> "Yes it is true that scientists used their creativity and imagination during experimentation because no one can do without thinking. When we use creativity, we think properly and do the work e.g. when Robert Hooke discovered like microscope. I think when he discovered this sort microscope he had many imagination and creativity to make the microscope." (S # 012 pre-questionnaire)

To develop students' views from naïve to informed views in creativity and imagination aspect of NOS, a total of two lessons were taught. The first one was using the decontextualized activity (mystery box) in Composition of Matter adapted from Bell (2008) and second in Laws of Conservation of Mass. This activity focused to teach and connect how scientists come up with model that help them to explain phenomena of things that can't be seen directly; either with the naked eye or with the help of instrument due to too small size (such as atoms, and organelles) or very far away distance (such as other galaxies and stars). Students were provided with magnet and stethoscope along with some questions to guide and were encouraged to work like scientists with the materials provided to them. During the activity all the students were fully engaged listening to the sound with stethoscope and using the magnets to find out whether the object inside the box was metallic. Students drew their interpretation and presented to the whole class. After the presentation the students were engaged in explicit and reflective discussion. Some questions discussed during are as mentioned below:

T: What did you do when you got stuck?

S: When we were stuck, we used different things and thought about other related instances and our past experience.

T: Do you think one observation is enough?

S: No, we need to make many observations.

T: So you make many observations to come to a conclusion.

T: During the investigation did you all use creativity and imagination.

S: Yes.

T: What did you imagine?

S: We tried to imagine the shape and the color of the objects inside the box.

T: How is your work related to the work of the scientists, if you were a scientist trying to find out answer to the question?

S: We used creativity and imagination and I think scientists also use their creativity and imagination.

T: Yes, scientists also use creativity and imagination in their work.

T: How were you able to infer the shape of the mystery object?

S: Listening to the sound that was making to observation, imagine, use creativity, past experience.

T: Did you make direct observation?

S: No, madam.

T: All the observations require interpretation and inference. Scientists need to use their creativity and imagination to make these inferences.

This activity helped students to understand that scientists do use creativity and imagination in all the steps of investigation/experimentation. In addition, teacher further emphasized indirect observation in science are often made when direct observation is insufficient for determining the unknown cases like when scientists cannot cut earth or sun in half, or see inside an atom. In such cases scientists must rely on indirect observation and inference, therefore, imagination and creativity is used to see an unseen object. However, this lesson was not enough for the student to develop their understanding about the role of creativity and imagination in science in all stages of scientific inquiry. The fifth lesson on Law of Conservation emphasized the role of creativity and imagination. Accordingly, the students were engaged in designing an experiment to see Law of Conservation of Mass followed by explicit and reflective discussion on scientific laws at the end of the lesson. In addition to these activities, a video clip was played about the work of Antoine Lavoisier on Law of Conservation of Mass. Students were then asked how their work were similar to the work of Antoine Lavoisier and compare what all things that they did were similar the work of a scientist. The question like, "Do you think what you have done is similar to work of scientists?" was posed at the students. The conversation between the teacher and the students during the discussions is as cited below:

T: So do you think what you have done is similar to work of scientists. (Here students were asked to compare what they have done like Antoine Lavoisier during their investigation).

S: Yes.

T: In What ways?

S: He predicated we also made prediction.

S: He had question in his mind.

T: And then after that?

S: So he had made observation

S: He tried to conduct the experiment

T: What else you have done is similar to his work?

S: He used many different instruments.

S: He tired many times.

T: Yes, Did you try many times?

S: Yes, madam.

T: What did he say about the numbers of times he conducted experiments.

S: He said that he has tried for many years.

T: Similarly you tried for many times to reduce the error.

S: He has evidences and we also have evidences.

T: What was your evidence?

S: Mass in the both case are same, It is same in the reactant and as well as in the product.

T: Though there were little because of your instrument.

T: What else did you do? How was your work similar to him?

S: We tried to investigate the mass of product and reactant after the reaction in a closed system?

T: Did you use creativity and imagination?

S: Yes.

T: Do you think scientists use creativity and imagination during the investigation?

S: Yes.

T: Which are the steps that you used creativity and imagination?

S: During designing and observation.

T: Only designing and observation.

S: No, when we collected the data, and analyzed the data also.

T: And then.

S: When we draw conclusions, when we designed and in all the steps.

T: So you think that scientists use creativity and imagination in all the steps of investigation.

S: Yes.

The most remarkable development noticed at the end of the intervention was in this aspect of NOS when compared with the rest of the aspect. At the beginning of the intervention only 44.4 % of the held informed views, however after the intervention 88. 9% of the students held informed views in the Likert part. Similarly, in the open-ended response only 5.6 % of the students held informed views, however, after the intervention 72.2% of the students held informed views. The majority of the students saw the role of creativity and imagination not only in the proliferation of new discoveries and invention but also throughout the scientific investigation after the intervention. Students' responses are mentioned below:

> "Scientist uses their creativity and imagination throughout their experiments during designing, collection of data, analyzing and drawing conclusion. E.g. to know the kinetic molecular theory of gas, molecules inside the container, scientist use their imagination and creativity through as the molecules can't be seen under ordinary conditions and also with compound microscope. It is also used in the step such as observation, forming hypothesis and collecting evidences in the form of data to come up with appropriate conclusion." (S # 03 post-instruction questionnaire)

> "Yes, surely when they are investigating and experimenting they use creativity and imagination. Example before the design they use creativity and they imagine drawing a conclusion. They are using when they are in doing such experiment, observation, analyzing data."(S#012 post-instruction questionnaire)

The students seemed to have developed understanding on the role of creativity and imagination required in all stages of scientific inquiry. For instance, one of the student (S # 015) wrote in her first journal, "Scientists use creativity and imagination while doing the experiments and to design new things" in the first journal after engaging students in mystery box activity. After the second lesson the same student wrote in the fifth journal, "Scientists use creativity and imagination throughout the investigations, for example, while designing, collecting data, analyzing data, drawing conclusion." On the outset, the development of students' views from naïve to informed views in the creativity and imagination aspect seemed to be remarkable as compared to rest of the aspect of NOS.

Scientific Method

In the beginning of the intervention, none of the participants held informed views as per data from both Likert-type items and open ended pre-instruction questionnaire responses. The majority of the students held transitional views both in the Likert scale (about 94.4%) and open-ended (about 88.9%) response. When individual Likert items were examined, 61.1% of the students' disagree on a statement "Scientists follow same step by step method" and "When scientist use the scientific method correctly, their result are true and accurate". In the open-ended responses of the pre-instruction questionnaire many students wrote that scientists used different types of methods but failed to mentioned examples of methods that scientists use.

> "No, they use different method because if one method is fail they will use different method to find the answer for the question."(S # 07 pre-instruction questionnaire)

> "No, scientist does not depend on only one method since they have their own ideas and knowledge to discover and prove many ways in unique ways." (S # 014 pre-instruction questionnaire)

> "Scientists follow different methods and ways to prove and conduct truth through reality. Depending on one method would not lead to success and proves what is true in reality." (S # 03 pre-instruction questionnaire)

Prior to the intervention, none of the students held informed views as per students' responses from the open-ended and Likert scale of the pre-instruction questionnaire. The majority of the students held transitional views. The student with transitional views knows that scientist use different type of methods but does not deeply understand what they actually are. In order to enhance students' views of NOS from naïve to transitional or to informed views, two lessons were designed. The first lesson was developed to teach scientific method based on the students' understanding of scientific methods during the scientific investigation from the previous lesson.

When teacher probed students' prior knowledge about the scientific method on how the investigation of the shape of an object inside the mystery box was different from the scientific step by step method through the question such as "Did you do use scientific step by step method?" and "Do you know what is meant by step by step?" Unfortunately, there were no responses which indicated that do not students understood the step-by step scientific method. Some parts of the class room discussion are as mentioned below:

T: Did you do an experiment here?
S: No.
T: In this case did you all do experiment using step by step scientific Method.
S: No response.
T: By the way do you know the step by step scientific methods?
S: No.
T: So you all don't have any idea about step by step scientific method.
S: No.

Further, students were asked, "Do you think scientists would conduct an experiment to find out what is inside the mystery box?" For example, if a scientist wants to find out what is inside an atom, can they cut open and do the experiment to see what is inside? "Will the scientists come to the similar conclusion about the identity of the mystery shape like you?" and "Do you think that you are 100 percent certain about the shape of the mystery object?" Some of the conversations between teacher and students during the explicit and reflective discussion session are mentioned below:

T: How is the process you have used to infer the shape of the mystery object is similar to the work of scientist/ physicists used to construct models of the atom?"
S: We made indirect observations and scientists also make indirect observations. (S # 08):

T: So you make the indirect observations, what else?

S: We used past knowledge and they also use the prior knowledge.

T: What else?

S: They used instrument and we also used instrument

T: What else?

S: Scientists use instruments and we also used instrument.

T: Yes and what else?

S: Scientists used their imagination and creativity and we have used our imagination and creativity to infer the shape of unseen objects inside the mystery box.

The teacher further explained in science there was no key answer. Through explicit discussions the students were made to realize that the experimentation is not only way involved in scientific investigation. Further, to ensure that students understand the use of diverse methods during the scientific investigation, a lesson on soda candy was adapted and adopted from Bell (2008) to teach students the steps in scientific method.

Teacher began the lesson by probing the students' prior knowledge about the experiment. Students referred experiment as a tool proving scientific knowledge. Further, teacher probed students' knowledge on hypothesis, variables, and controlled experiment; unfortunately students were not able to answer. The teacher then explained the meaning of an experiment and various steps involved in scientific method. Once the students understood the literal meaning of terms like experiment, hypothesis, dependent variables and independent variables and controlled experiment then teacher let the students to predict what would happen when the Mentos candy is dropped in the diet coke? During this activity, students were also asked to identify each step during the experimentation. At the end of the lesson an explicit and reflective discussion was led by the teacher to draw students' attention on using diverse methods in science that gave an opportunity students to reflect back on what they had learnt in the previous lesson especially, mystery box activity which focused in indirect observations without using step by step scientific method. Some of the conversation between students and teacher during the explicit and reflective discussion is mentioned below:

T: Let us look at the back on the mystery box activity and try to compare with each other. While investigating the shape of an object did you use the same methods?

S: No

T: Can you give some example of different scientific methods where we cannot use step by step method or universal method?

S: When we investigate interior of the earth we cannot follow step by step method.

T: Where else?

S: Studying of atom structure.

T: Can you give some example of different types of method scientists' use?

S: Indirect observation, imagination and creativity.

T: Yes, there are many more, like experimentation, library investigation, compare, measure, use mathematical representation, and take photograph.

The response from the Likert part and open-ended response from post-instruction questionnaire showed that there was less substantial development of students' views observed in this aspect. Prior to the intervention only 5.6% of the students held informed views and at the end of the intervention 7(38.9%) of the students held informed views. Coming to the individual Likert items, there was no development seen especially in two items. Prior to the intervention, 61.1% of the students' disagreed on this statement "Scientists follow the same step by step method" and after the intervention 72.2% of the students disagreed. For instance, prior to the intervention and after the intervention, one of the students (S#02) responded,

> "Scientists follow a single scientific method because in universal method scientists gather and proved the method and use." (S # 02 Pre-instruction questionnaire)

> "Scientist follows different type of method because sometimes it may form wrong answer and also is some situation it may not be suitable for universal method. [For example] to study kinetic molecular theory, structure of atoms we cannot use universal method." (S # 02 post-instruction questionnaire)

Similarly, another student (S#06) in the pre-intervention interview responded:

> "I think scientists use different method during the scientific investigation. If one method does not work other might work. For example, to make a tea whether we add milk, sugar or tea leaves first or tea leaf first and the sugar and milk the outcome becomes the same i.e. tea only. The method may be the different but the outcome is the same."

The same student (06) after the intervention in the post semi-structured interviews said:

> "Scientists use different methods, if they are going to investigation on our earth or different planets. They will not use step-by step scientific methods because if they use step-by-step scientific methods they will not get accurate answer, they might face many errors, so scientists don't use step by step method in all scientific investigation. They use observations, for example, if they want to look at how earth is developed they mightily they go to the outer space to observe the shape of the earth, take a photograph and after reaching back to earth they might use instruments to check the soil structures."

At the end of the intervention, there were some developments observed in students' views. However, the development seemed to be less substantial as compare to other aspects of NOS except social and cultural embeddedness.

Empirical Nature of Scientific Knowledge

In answer to “What is science?” “What makes science different from other discipline of inquiry (example, religion, Philosophy)?” the majority of the students held transitional views both in the Likert and open-ended responses, prior to the intervention. In the Likert part about (94.4%) of the students held transitional views. On the closer examination of the sub-scale items, the majority of about 66.7% believed that “scientists make sufficient observation and measurement to reduce error and obtain reliable evidence.” In another Likert sub-scale, 55.5% of the students disagreed on the statement “scientists invent scientific knowledge, so it does not need observable evidence.” Interestingly, many of these students perceived science as subjects, products of science knowledge and science that exits around them especially, about the study of living and non-living things and the environment around but failed to mention scientific knowledge is based on empirical evidence supported by observation and inference prior to the intervention. Some of the students viewed science as:

> “From my view science is a study of all living and non-living things and also study of all the matter present in the universe. I think religion, philosophy makes science different because from religion it gives different reason and by science it gives proved and accurate reason.”(S #05 pre-instruction questionnaire)

> “Science is a subject where we learn different view about the nature and the world. Science is different from other discipline because in science we learn about many other things [which] we don’t know about the thing.” (S # 07 pre-instruction questionnaire)

> “In my view the science is the learning of nature and function of the nature science is different from other by knowing how the work is going for example how the flowers have grown so bright because of good function inside and investigating the flower.” (S # 02 pre-instruction questionnaire)

Although, the majority of the students held transitional views, there were some students with the naïve views. These students perceived science as learning about truth which made science different from other disciplines of inquiry.

> "Science is in our view that science is truth science is proved by its facts." (S # 08 pre-instruction questionnaire)

> "Science is which study about truth, science make different from other because science have been proved by its facts." (S # 011 pre-instruction questionnaire)

As mentioned earlier, prior to the intervention the majority (66.7 %) of the student held transitional views. These students viewed science as study of the product of science and saw science as what they have learnt in biology classes. For instance, many students mentioned about the study of living, non-living, and environment around them. To develop students' views in this aspect of NOS, students' attention was drawn explicitly in two lessons (Motion in liquids and Boyle's law). Before the introduction of mystery box activity, students' prior knowledge about science was probed. Surprisingly, the majority of the students said that science is all about truth and everything in science is true and facts while other students said, "Science is study of living things and non-living and the environment.

Lesson 3 on molecules in motion was taught through guided inquiry followed by explicit and reflective discussion on empirical nature of scientific knowledge. The lesson started with an activity that demonstrated the motion of liquids. Few drops of ink were dropped in a beaker of water. Students were also asked to imagine the movements of the particles through a magic glass and draw the particle in their note book. Then teacher posed questions. (1) Is speed of water molecules different in hot water and cold water? (2) What can we do to find out? Student worked in group to design an experiment to investigate the speed of molecules in hot and cold medium. Students were also reminded to keep in mind about the variable that they are going to keep same. For example, same amount of hot and cold water, same amount the coloring material and the same time you drop the ink in the beaker are to be taken note. After student completed their designing, the teacher ensured the safety in the experiment. At this point the importance of revising and modification of the procedure is important for the scientists to reduce error. Teacher tried to connect students' work with the work of scientists when they want to explain an event. Scientists connect observations, scientific concept and principles in a reasonable way to make sense of the observation. When scientist proposes an explanation they use scientific knowledge and observational evidence to support their explanation. Similarly, students were told to check their explanation against scientific knowledge, experience, and observations of others. Students were not able to design, teacher constantly guided the students to write hypothesis, and design an experiment. At the beginning there was lots of confusion that created lots of chaos in the class. Some of the conversation that explicitly drew students' attentions after the presentation are mentioned below:

T: How did you know that the movement of the molecules is faster in hot water?

S: From the observations.

T: How did different piece of evidence support you conclusion?

S: We observed that the ink the movement of particles in hot water and as different.

T: So what is important in science?

S: Observation and inference is important in science.

T: What about the evidence in science?

S: Yes, it is important.

T: What conclusion have you all drawn now?

S: The speed of the molecule is faster in hot water as compared to the cold water.

The second lesson on Boyle's Law focused to teach empirical nature of scientific knowledge. During Boyle's law activity, students were asked, "How does pressure relates to volume?" With this question students were to design an activity to find relationship between volume and pressure. Students were also encouraged to write the hypothesis like: If pressure is __, then volume is __ Students were also asked to write the procedure, results data collected and make graphic representation. At the end of the presentation, the teacher led the explicit and reflective discussion which gave an opportunity for the students to reflect the empirical nature of scientific knowledge. Some of the discussions that took place are as recorded below:

T: How was your approach to investigation volume and pressure gas similar to what scientists do study the natural world?

S: First we tried to go to the library and did some research.

We tried to design the procedure to investigate the relationship between the volume and the pressure

T: What else did you all do?

After designing we discussed with madam and then others friends.

T: What about group three students?

S: We tried to do the experiment.

T: Then what else did you do?

S: We collected the data and plotted in the graph.

S: We draw conclusion from the graph and concluded.

T: Now what is you conclusion?

S: When pressure increases the volume decreases.

T: How did you use different evidence to support your conclusion?

Group 2: (chorus) We tried using different amount of load (like books) we observed the volume decreased when we increased the load.

Group 2: We plotted the line graph, volume and pressure that showed with the increase in pressure the volume decreases.

T: Do you think the empirical evidence that you got proves scientific claims or support the scientific claims?

S: (No responses)

T: Empirical evidence supports scientific claims but does not proves in absolute sense.

However, after the intervention, there was substantial development from transitional views into informed views in this aspect as compared with other aspects of NOS of this study. After the intervention, 61.1% of the students showed the informed views in the Likert scale. Similarly, in the open-ended post-questionnaire, the percentage of students who developed their views to informed views increased from 5.6% to 66.7% after the intervention. The words like proof, facts and truth were not seen much in the students' responses in the post-questionnaire responses when compared to the responses from the pre-questionnaire. Majority of the students viewed science as a body of knowledge or the study of the natural phenomena from which scientific knowledge are generated. Furthermore, they believed that science demands empirical evidence, observation and inference. Students did not see science as a product of scientific knowledge and that science exits around them. Some of the students' responses are mentioned below:

"Science refers to the study of information of all the natural phenomena that is in and around the nature. As science demands observation, inference and lots of evidence to support the investigation, whereas religion and philosophy only refers to believes and faith and devotion."(S # 06 post-instruction questionnaire)

"In my point of view science is the knowledge of the natural world that are happening around us and around our environment. Science is different from other religion because science demands lots of empirical evidence and inference, observation hypothesis, conclusion and experiment/ scientific method which other don't demand it."(S # 013 post-instruction questionnaire)

At the beginning of the study during mystery box activity when students were asked, "What science is?" The majority of the students said, "Science is about truth. Everything in science is true." Similarly, the open-ended responses in the pre-instruction questionnaire, many students viewed science as study of truth. From instance, one student (S # 011) mentioned that "Science is that which studies about truth, science make different from other because science have been proved by its facts.” However, after the intervention the same student changed his views about science. He said, “Science means study about natural world and the process through which the knowledge is built. Observation, inference and evidence make it different from other disciplines inquiry.” At the outset, majority of the students developed from transitional views to informed views after the intervention. Students seemed to see science as a body of knowledge that demands empirical evidence, observation, inference to support the investigation and it is different from other disciplines because it requires empirical evidence.

Summary

In general, both qualitative and quantitative data showed that the majority of the students held naïve views in scientific theories and laws, social and cultural embeddedness and tentativeness aspects of NOS. In other aspects like observation and inference, empirical of nature of scientific knowledge, scientific methods, and creativity and imagination, majority of the students held transitional views. On the whole, a minority of the students held informed views in all the aspect of NOS as per the analysis of the phase 1 data. After the intervention students have developed either from naive to transitional or from transitional to informed views in all the aspects of the NOS included in this study although the development was not parallel in all the aspects.

CHAPTER V

CONCLUSIONS, DISCUSIONS AND RECOMMENDATIONS

Background of the Study

Scientific literacy has become central goal of science education across the globe (AAAS, 1990; NRC 1996). The present study was undertaken since scientific literacy is one of the goals of science education based on the new Science Curriculum Framework in Bhutan. Many researchers (e.g., Meichtry, 1993; Driver *et al*., 1996; AAAS, 1989; NRC, 1996) pointed that NOS is one of the key components of scientific literacy. Helping to promote teachers' and students' informed views of NOS are major concern taken by many science educators around the world. As mentioned earlier in chapter one, with coming up of new science curriculum, NOS has just emerged in Bhutan's science literacy in an implicit manner. The process as to how science works, investigation and experimentation are merged together as working scientifically where Bhutanese students are expected to understand NOS automatically when the science lessons are being delivered through inquiry oriented approach (DCRD, 2012). However, many researchers (e.g., Abd-El-Khalick, Lederman, 2000; Abd-El-Khalick, 2001; Khishfe and Abd-El-Khalick, 2002; Khishfe, 2008; Bell, Matkins, and Gansneder, 2011; Lederman and Abd-El-Khalick, 2002; Bell and Abd-El-Khalick, 2012; Yacoubian and Boujaoude, 2010) found that explicit-reflective approach increases the effectiveness of understanding NOS both in students and teachers approach. Since, no research has been conducted in Bhutan in exploring students' views of NOS. This study focused to explore and enhance Bhutanese students' views of NOS through two phases of study.

A survey research was conducted to explore grade nine students' views in seven aspects in NOS in 14 schools in four regions of Bhutan under phase 1. The results from this phase were taken as baseline to develop the phase 2. In phase 2, a case study was conducted with a total of 18 ninth grade students from one section of grade nine in one of the higher secondary schools in Bhutan. Six lesson plans were taught through using guided inquiry and one lesson was taught through use of the history of scientists. During the intervention, seven aspects of NOS namely: tentativeness of scientific knowledge; the empirical nature of scientific knowledge; observation and inference; creativity and imagination; scientific theories and laws; scientific methods and social and cultural embeddedness were integrated in chemistry lessons. The intervention was of 6 weeks duration in the beginning of the academic session, 2014.

Conclusions

At the outset, the results from the phase 1 provides broader picture of students' views of NOS in the current situation. Both qualitative and quantitative data from phase 1 showed that the majority of the students held naïve views in scientific theories and laws, social and cultural embeddedness and tentativeness aspects of NOS. Particularly in scientific laws and theories aspect of NOS, none of the students held informed views both in the Likert scale and the open-ended questions. In other aspects of NOS like observation and inference, empirical of nature of scientific knowledge, scientific methods, and creativity and imagination, majority of the students held transitional views. However, not many students held informed views in all the aspect of NOS. These results indicate that ninth grade Bhutanese students held inadequate views of NOS and many of the naïve views are similar to the ones recognized in high schools students of many other countries. For instance, scientific laws and theories have been proven depending on the availability of the empirical evidence.

Phase 2 of this study was aimed to develop students' views of NOS into informed views through integration of NOS aspects in chemistry lessons as mentioned earlier. The result of phase 2 was encouraging to look at the positive results which revealed that the explicit and reflective instructional approach was effective in enhancing ninth grade students' views of NOS. Prior to the intervention, the majority of students held inadequate views on all the aspect of NOS. However, after the intervention developments in students' views in all aspects of NOS was observed but were in parallel. It is evident that explicit and reflective approach is good way to enhance students' views of NOS.

Discussions

The views of NOS among Ninth Grade Bhutanese Students

The results from the phase 1, i.e. the survey conducted to explore the views of NOS among ninth grade Bhutanese students, indicated that the majority of ninth graders held inadequate views in all seven aspects of NOS. Both qualitative and quantitative data showed that the majority of the students held naïve views in scientific theories and laws, social and cultural embeddedness and tentativeness aspects of NOS. Particularly, in law and theory aspect of NOS, none of the students held informed views both in the Likert scale and the open-ended responses. However, in other aspects like observation and inference, empirical nature of scientific knowledge, scientific methods, and creativity and imagination, many students held transitional views. In general, not many students held informed views in all the aspect of NOS. These students might have gained some knowledge from the textbooks, from the teachers or through media. Although, at large, only few students held informed views which showed these results are consistent with the previous research studies that assessed junior and high schools students' views of NOS (e.g., Dogan and Abd-El-Khalick, 2008; Ryan and Aikenhead 1992; Kang, *et al.,* 2005).

In the tentativeness of nature of aspects of NOS, students showed more informed views (about 21.4%) then the rest of the aspects as seen in the open-ended responses. Students were able to give examples from the periodic table and atomic theory that they learned from grade nine chemistry textbooks. These students seemed to understand tentativeness more than other aspects of NOS. On the other hand, a common misconception, "an absolutist views" were also seen in open-ended responses similar to many other researchers findings (e.g., Kang, Scharman, and Noh 2005; Rubba, 1977). Students holding absolutist views of NOS are likely due to motivation on the performance on examination that leads to rote learning and memorization of facts (Cavallo *et al*., 2003; Tsia, 1998a).

Regarding social and cultural embeddedness aspect of NOS, the majority of the students viewed science as independent from social and cultural values both in the Likert scale and the open-ended response. These students believed that scientific knowledge and research deals with nature, scientific truth but social and culture are related to religion and beliefs as a result scientists' work is not affected by culture and society. For these students the work of scientists seemed excavating the truth which is not influenced by social and cultural values. The underline fact is that Bhutan has unique traditions and culture and Bhutanese value it above everything. Since all Bhutanese are guarded by this nationalistic view of life, students take culture very strongly in a protectionist sense and which may have contributed students to perceive science as independent from social and cultural values. Moreover, since "Myth and tradition are an important part of Bhutanese culture, enshrined in the dimension of GNH, and their inclusion in the science curriculum is important part of the country's development plan" (Childs *et al.*, 2012*:* 394). It is important to make the students understand that social and cultural values can impact the scientific research being done or being carried out. Furthermore, Kelly (1993) argues that the social conditions and political commitment of a society deeply influence science. In fact, science is the product of culture that produces it and it is very important to let the students understand science as a product of the culture that produces it and not to assume that science can achieve conclusion independently from the large social context in which it works.

The results in the scientific theories and laws seemed to be overwhelming. None of the students held informed views in both Likert scale and the open-ended response. It seemed that students are not able to see the correct relationship between scientific theories and laws. Students believed that scientific laws are theories that have been proven depending on the availability of the empirical evidence and then becomes laws. Basically, this hierarchical misconception is associated with an idea that theories become laws. This result is similar to other findings (e.g., Rubba, 1977;

Rubba and Anderson, 1978; Ryan and Aikenhead, 1992; Abd-El-khalick, 2006). On the other hand, some students viewed scientific laws as the rules that the scientist follow during the scientific investigation, another misconception noted due to the language.

Looking at the empirical nature of scientific knowledge, the majority of the students viewed science as learning of materials around them, about the products of scientific process and as an academic subject. Indeed, these views in students could be due to the fact that most of the teachings in grade 9 and above are lectured based where students do not get an opportunity to engage in scientific inquiry process. Moreover, Johnson *et al.* (2008) in their study found that physics, chemistry, and biology subjects are content loaded in grade nine to grade twelve that results in conducting practical mostly separately to confirm theory learnt. Moreover, having to prepare students to achieve higher score in the national examination in grades 3, 6, 10, and 12, teachers often choose to explain in a single lecture to complete the syllabus on time, could be one of the factor that might have made students to see science as the product of science. Furthermore, students' inadequate view of NOS is likely because of the textbooks, inappropriate experience provided in the classroom, teachers' inadequate views of NOS, and the ineffectiveness of curricula as concluded by other researcher (e.g., Lederman, 2007; Abd-El-Khalick, 2003). The role of science educators and teachers is not only to present science as the only way of knowing but also facilitate students' understanding of science so that they can make sense of the way in which the scientific concept are generated and validated. As mentioned earlier, students' understanding of NOS is one of the key components of scientific literacy in science education programs (Lederman, 1992; McComas and Oldon, 1998). Helping students and teachers to have an adequate understanding of NOS is one of the major concerns around the globe and it should be in Bhutan too.

Development of Students Views of NOS

The enhancing students' view on NOS is the central goal in science education around the globe. Phase 2 of this study was aimed to enhance ninth grade students' views of NOS through integration of aspects of NOS in two units: Matter and Its composition and Study of Gas Law through explicit and reflective approach. The results from this study indicated that students' views of NOS had changed from naïve to transitional views or informed and from transitional to informed views in all the aspects of NOS after the intervention. This result is consistent to other studies (e.g., Bell *et al*., 2002; Khishfe and Abd-El- Khalick , 2002; Khishfe and Lederman, 2006; Khishfe, 2008; Abd-El- Khalick,2001; Abd-El- Khalick *et al*.,1998; Bell *et al*., 2010) who supported that explicit and reflective approach of teaching NOS improve students' and teachers' of views NOS. However, the development in all the aspects of NOS was not parallel as eight weeks of duration was not enough to develop into fully informed as argued by Faikhamta (2012). For instance, in some aspects like creativity and imagination, observation and inference, empirical nature of scientific knowledge a substantial gain. However, development of students' views in social and culture embeddedness aspects of NOS was less substantial. Prior to the intervention Table 4.3 88.9 % of the students held naïve views, 11.1% held transitional and none of the students held informed views. However, after the intervention only 27.8% of the students held informed, the majority of the students about 61.1% held transitional views. The results showed that the development of students' views of NOS was not parallel with all the aspects. The reason could be because of the fact that this aspect was integrated only in one lesson due to the nature of content. This indicated that the development of students' views of NOS depends as per the nature of instruction and quantity of the instructions that has been devoted to that particular aspect as pointed by Khishfe (2008) and Brickhouse *et al*., (2000).

As mentioned earlier, there were variations in the development of the students' views in each aspect of NOS. For instance, a substantial development was noted is students views in tentativeness, observation and inference and creativity and imagination aspect of NOS was introduced with a decontextualized activity and followed by inquiry approach. The responses from the pre-instruction questionnaire indicated that 5.6 % of the students held informed views and post-instruction questionnaire indicated that 66.7 % of the students held informed views, which showed a substantial development in students' views in creativity and imagination aspect of NOS. Similarly, in tentativeness and observation and inference a decontextualized activity (mystery box activity) was introduced in this aspect of NOS. Clough, (2006) pointed that explicit decontextualized NOS instruction has a role play in drawing students' attention to particular NOS issues and initiating deep cognitive processing. A decontextualized activity can provide a solid foundation that can link contextualized NOS instruction.

Shulman (1987) introduced the concept of pedagogical content knowledge (PCK) and according to Shulman (1987: 8) PCK is "Special amalgam of content and pedagogy that is uniquely the province of teacher, their own special form of professional understanding." It is the blending of pedagogy and subject matter (content knowledge) including the understanding of how a particular topics, problems, or issues could be organized and represented to different learners with different abilities and different interest. The model of Shulman (1987) was later elaborated by other scholars (e.g., Grossman. 1990; Magnusson, Krajcik, and Borko, 1999). Later Magnusson *et al.* (1999) elaborated PCK for teaching science into five components namely: orientations towards science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science, knowledge and beliefs about assessment in science and knowledge and beliefs about instructional strategies for teaching science. NOS is considered as a subject-specific content because of its own concepts, technical terms and topics (Faikhamta, 2012). Indeed, teaching NOS is very challenging as stated by science educators (e.g., Abd-El-Khalick and Lederman 2002; Faikhamta, 2012). Knowledge of NOS is not enough to teach NOS effectively (Schwartz and Lederman 2002; Lederman, 1999). I as a researcher and a teacher teaching NOS have experienced that in order to address NOS in the classroom successfully one need to have PCK for teaching NOS as proposed by Schwartz and Lederman (2002), where three domains pedagogical knowledge, NOS knowledge and good subject knowledge must be interwoven to teach NOS effectively. Indeed, sound understanding of the knowledge of NOS and the content knowledge is not enough to teach NOS. To teach NOS effectively, the teacher need find out an appropriate strategy as per the nature of the content. For example, in this study social and cultural embeddedness and tentativeness aspect of NOS was taught with historical approach. Similarly, scientific laws and theories were taught with inquiry learning while studying Boyle’s law and Charles’ law and the kinetic molecular theory of gas.

Another key point noticed during the intervention was letting students watch appropriate video clips on the work of scientists and then letting them to compare the work of scientists with their own work seemed to help the students to portray the work of scientists. Or when students were involved in investigation, teachers' questions like ‘how their work is similar to that of the scientists.’ For example, in this study when law of conservation was taught a video clip was shown and students were asked to compare how their investigation on law of conservation of mass was similar the work of Antoine Lavoisier on the discovery of law of conservation of mass. In addition, revisiting of NOS aspects before beginning the lesson also helped the students to understand and retain NOS aspects.

Language is one the issue that leads to misconception understanding NOS. For example, when students were asked to define scientific laws, the majority of the students defined scientific laws are the ‘rules’ that scientists follow when they do scientific research or investigations. Another common misconception noticed was understanding inference as interference, prove as absolute truth. This shows that the language that teacher use while teaching science content is important in fostering informed views of NOS.

Unlike in other countries, Bhutanese students in the pre-instruction responses majority of the students believed that scientists use different method during the scientific investigation but these students were not able to say different types of method involved. However, during the intervention when students were asked about the various steps involved in scientific method, it was found that students were unaware of the various steps involved. Students knew only about the experiments. This could be because in grade seven and grade eight the students learn integrated science and the teaching is mostly teacher led and the students rarely get opportunity to be engaged in the scientific investigation or discussion. However, after the intervention many students held informed views.

As mentioned earlier, prior to the intervention majority of the students held naïve views and after the intervention, 27.8% of the students held informed views in social and cultural embeddedness aspect of NOS. The majority of the students believed that science is independent of society. Since one of the objective that students must fulfill after completing ninth grade as per the new science curriculum is that “Students should be able give examples of the ways in which scientific work may be affected by social, historical and cultural contexts in which it takes place, and how these contexts may affect whether theories and ideas are accepted” (DRCD, 2012:23). Moreover, many researchers (e.g., Abd-El-Khalick *et al*., 1998; Bell *et al*., 2000) pointed that social and cultural embeddedness aspect of NOS is difficult for the students to understand.

Recommendations

As mentioned earlier NOS is one of the components of scientific literacy. Clough (2000) pointed that deficiency in scientific literacy is due to lack of understanding of NOS by teachers and students which in turn could impact attitudes and future learning of science. The results from this study indicated that Bhutanese students held inadequate views of NOS. As science teacher as well as a researcher, I realized that there is a necessity to emphasize on the explicit approach as an alternative to develop students’ views of NOS rather than through implicit approach where by Bhutanese students are expected to understand NOS automatically when science lessons are delivered through inquiry learning. When given an opportunity to learn NOS through explicit and reflective approach, Bhutanese students’ views of NOS had changed NOS views from naïve to transitional or informed or from transitional to informed. The policy makers, science educators need to see the importance of teaching NOS and explicitly emphasize to teach NOS rather than implicit approach.

Teaching NOS effectively is not simple. Researchers (like Abd-El-Khalick and Lederman, 2000a; Meesri, 2007) pointed that having informed views of NOS is important but not sufficient enough for the teachers to address NOS instructionally. Learning of NOS has just appeared in Bhutanese science education and it is very new to almost all teachers and students except the first batch of four-year bachelor of primary science who were enrolled in 2009 after the introduction of four year course. Although NOS is taught briefly to the pre-services teachers in four-year bachelor of education in primary science module in general NOS is quite new to Bhutanese students and teachers, and this being the first research conducted in this field, more researches is expected to be conducted at different grade level, in-service teachers, and pre-service teachers. The findings of study suggest that to let the pre-service teachers understand NOS is not enough but prepare them teach them to NOS integrate in the lessons as done in this study. In addition, NOS could be also introduced in four-year bachelor of education for secondary and post-graduate diploma, one year program. To help pre-services and in-service teachers to integrate NOS in the lessons, PCK for NOS could be developed which in turn can contribute to produce scientifically literate citizens that Bhutan aspire for underpinned by Gross National Happiness principles. Due to the intimate relationship between scientific literacy and NOS, science educators around the world have given importance in devolving and implementing appropriate science curricula that helps in students understanding of NOS (McComas and Olson, 1998).

In the international perspective, I as researcher and as well as the teacher teaching NOS have realized that having an informed views of NOS in not sufficient to address NOS in the instruction in the classroom. In order to teach NOS effectively, the teacher need have to PCK to teach NOS (Kim *et al*., 2005; Schwartz and Lederman, 2002). Schwartz and Lederman (2002) claimed that to teach NOS effectively in classroom, teachers must have PCK for teaching NOS i.e. having strong subject-matter knowledge, strong knowledge of NOS, and pedagogical knowledge and interaction of these three domains. They also pointed out that building teachers' PCK for teaching NOS may lead to students' achievement as desired, if teacher to students' achievement as desired, if teacher internalize the importance of teaching NOS. Furthermore, Faikhamta (2013) suggested that PCK based course can enable the in-service teachers to consider various aspects of NOS according to PCK components including learning outcomes, NOS in science curriculum, students learning conceptions of NOS, constructivist- based teaching strategies, assessment of student learning and how to make certain features of NOS explicit to students. The science educators, professional developers need to take lead role to help teachers to develop PCK for NOS.

In social and cultural embeddedness aspects of NOS there was less substantial gain as compared to the rest. It is difficult for the students to understand this aspect, which is many science educators (e.g., Abd-El-Khalick *et al*., 1998; Bell *et al*., 2000; Khishfe and Lederman, 2006) expressed. Moreover, there are few studies which investigated middle secondary and higher students' views in social and cultural embeddedness aspects of NOS. Further research could be conducted integrating social and cultural embeddedness aspect of NOS in the Asian countries or culturally rich countries. This would help science educators, teachers to help students to understand the social and cultural embedded aspect of NOS and understand science as human endeavor which is product of the culture that produces it and not to assume that science can achieve conclusion independently from the large social context in which it works.

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APPENDICES

Appendix A

Questionnaire

Appendix Table 1 Questionnaire

Student Understanding of Science and Scientific Inquiry Questionnaire

Name:

School:

Date:

Instructions

Please answer each of the following questions. There is no right or wrong answers. In this questionnaire there are two parts in each question. For the first part please read EACH statement carefully, and then show the degree to which you agree or disagree with EACH statement by circling the appropriate letters to the right of each statement (SD= Strongly Disagree; D= Disagree; More Than Agree; U= Uncertain or Not sure; A = agree More Than Disagree; SA= Strongly Agree). For the second part, write the answer in the space provided. Make sure you answer all the questions

1	Observations and Inferences					
A	Scientists' observations of the same event may be different because the scientists use earlier experience and knowledge may affect their observations.	SD	D	U	A	SA
B	Scientists' observations of the same event will be the same because scientists think in the similar way.	SD	D	U	A	SA
C	Scientists' observations of the same event will be the same because observations are facts.	SD	D	U	A	SA
D	Scientists may make different interpretations based on the same observations.	SD	D	U	A	SA

Do you think all scientists' observation and interpretations are same or different? With example, explain why you think scientists' observations and interpretations are same or different.

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Appendix Table 1 (Continued)

2	Change of Scientific Theories					
A	Scientific theories are subject to on-going testing and revision.	SD	D	U	A	SA
B	Scientific theories may be completely replaced by new theories when new evidence is found.	SD	D	U	A	SA
C	A new interpretation of data can change our present scientific knowledge.	SD	D	U	A	SA
D	Scientific theories based on accurate experimentation will not be changed.	SD	D	U	A	SA

After scientists develop a scientific theory (for example, cell theory, atomic theory, evolution theory, etc.) does the theory ever change? With examples, explain why you think scientific theories do not change OR how (in what ways) scientific theories may be changed.

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3	Scientific Laws vs. Theories					
A	Scientific theories exist in the natural world and are discovered through scientific investigations.	SD	D	U	A	SA
B	Scientific theories can change but scientific laws do not change.	SD	D	U	A	SA
C	Scientific laws are theories that have been proven.	SD	D	U	A	SA
D	Scientific theories explain scientific laws.	SD	D	U	A	SA

Is there a difference between a scientific theory and a scientific law? Illustrate your answer with example.

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Appendix Table 1 (Continued)

4	Social and Cultural Influence on Science					
A	Scientific research is not influenced by society and culture because scientists are trained to conduct “pure”, unbiased studies.	SD	D	U	A	SA
B	Cultural values and expectations determine what science is conducted and accepted.	SD	D	U	A	SA
C	Cultural values and expectations determine how science is conducted and accepted.	SD	D	U	A	SA
D	Science is not influenced by cultural and societal values because science is independent of society and culture.	SD	D	U	A	SA

Do you think social and cultural values decide what scientists should work on?

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5	**Imagination and Creativity in Scientific investigation**					
A	Scientists use their imagination and creativity when they collect data.	SD	D	U	A	SA
B	Scientists use their imagination and creativity when they analyze and interpret data.	SD	D	U	A	SA
C	Scientists do **not** use their imagination and creativity because these conflict with their rational reasoning.	SD	D	U	A	SA
D	Scientists do **not** use their imagination and creativity because these can interfere with objectivity.	SD	D	U	A	SA

Scientists perform investigations/experimentations while trying to find out answer to questions. Do you think scientists use creativity and imagination during investigations/experimentations? With examples, explain how and when scientists use imagination and creativity **OR** do not use imagination and creativity.

Appendix Table 1 (Continued)

6	**Methods of Scientific Investigation**					
A	Scientists use different types of methods to conduct scientific investigations.	SD	D	U	A	SA
B	Scientists follow the same step-by-step scientific method.	SD	D	U	A	SA
C	When scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
D	Experiments are not the only means used in the development of scientific knowledge.	SD	D	U	A	SA

With examples, explain whether scientists follow a single, universal scientific method **OR** use different type of method. For example the universal method means such steps as defined the problem → gather information→ form a hypothesis→ make relevant observations form hypothesis →make relevant observations →test hypothesis→ form conclusions → results.

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7	**The Empirical Nature of scientific Knowledge**					
A	Scientists make sufficient observations and measurements to reduce error and obtain reliable evidence.	SD	D	U	A	SA
B	Among different scientific theories, the acceptance of scientific theory depends on experimental evidence.	SD	D	U	A	SA
C	Scientists use only one direct evidence such as observational or experimental data to explain the natural world works.	SD	D	U	A	SA
D	Scientists invent scientific knowledge, so it does not need observable evidence.	SD	D	U	A	SA

What, in your view, is science? What makes science different from other fr disciplines of inquiry (e.g., religion, philosophy)?

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Appendix B

Taxonomy of Views about Nature of Scientific Knowledge

Appendix Table 2 Taxonomy of Views about Nature of Scientific Knowledge

Aspects of NOS	Description	
Observation and Inference	Science is based on observation and inference. Observations are simple statements that describe the natural phenomena which are directly accessible to the senses. On contrary, inferences are statements about phenomena that are not directly accessible to the senses. Inference are thee logical conclusion based on observation. Observation and inference are guided by scientist's prior knowledge and current perspective of science.	1A (+) 1B (-) IC(-) 1 D(+)
Tentativeness	Scientific knowledge is reliable and durable but is not absolute and certain. Scientific claims, theories, laws are subject to change. Scientific knowledge therefore, can be modified, disproved or approved in the light of new evidence made possible through advancement in technology and new interpretation of the data.	2A (+) 2B (+) 2C(+) 2D (-)
Scientific theories and laws	Scientific theories are well-established sets of concepts that can explain observations based on more than one investigation. More importantly, theories play big roles in generating research problems and enquiries. Therefore, theories are based on probable assumptions which make theories not directly testable. For example kinetic molecular theory explains the phenomena related to the change in physical states of matter. On the other hand, laws describe the relationship between observable phenomena. For example, Boyle's law relates the pressure of a gas to its	3A (-) 3B (-) 3C (-) 3D (+)

Appendix Table 2 (Continued)

Aspects of NOS	Description	
	volume at a constant temperature. Theories do not become laws even with additional evidence; they explain laws Therefore, theories differ from law as they are inferred explanations for observable phenomena.	
Social and cultural embeddedness	Science is a human endeavor and is influenced by historical, cultural and social events and science cannot be separated from it since every scientific knowledge has to be digested ultimately by humans who are in turn abided by historical, cultural and social laws. The values and expectation of a culture are determined by what and how science is conducted, interpreted, and accepted. Therefore, science and society are interwoven and inseparable to the extent that some scientific studies are even barred by social norms.	4A(-) 4B(+); 4C(+); 4D(-)
Creativity and Imagination	Scientific knowledge does not just emerge only from experiment and data analysis. The development of scientific knowledge involves making careful observations of nature and natural phenomena. Science, contrary to common belief, is not a lifeless, entirely rational, and orderly activity in generating scientific knowledge, involves human imagination and creativity. The leap from atomic spectral lines to Bohr's model of the atom with its elaborate orbits and energy levels is an example. This aspect of science, coupled with its inferential nature, entails those scientific entities such as atoms and species are functional theoretical models rather than faithful copies of reality.	5A(+); 5B(+); 5C (-); 5D (-)

Appendix Table 2 (Continued)

Aspects of NOS	Description	
Scientific methods	Different types of scientific knowledge are investigated through various kinds of scientific methods. There is no single step by step universal scientific method to do science. Scientists investigate research question prior knowledge, creativity and perseverance. Scientists uses a variety of methods and approaches to generate scientific knowledge, including observation, inferences, experimentation, speculation, library investigation, hypothesize, create ideas and construct theories and explanations.	6A(+); 6B (-); 6C(-); 6D (+)
The Empirical Nature of scientific Knowledge	Scientific knowledge is derived based on natural phenomena, evidence, and observation of the world around us with an interpretation. Science is not fully based on observations of the natural world as its findings at the end should be settled by referring to observations of phenomena'' (AAAS, 1990). However, most of the time scientists do not get a direct access to most of the natural phenomena. Scientist uses their senses and or sophisticated instrumentation in order to draw realistic and believable conclusion.	7(A(+); 7B(-); 7C(-); 7D(-)

Source: (NSTA, 2000; AAAS, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Liang *et al*., 2005; 2008)

Appendix C

Students’ Response from the Likert Scale from Phase 2

Appendix Table 3 Students' response from the Likert scale from phase 2

	Pre-instruction Questionnaire			Post- instruction Questionnaire		
Aspects of NOS	**SA and A**	**U**	**D and SD**	**SA and A**	**U**	**D and SD**
Observations and Inferences						
Scientist's observations of the same event may be different because the scientists use earlier experience and knowledge may affect their observations.	15(83.3)	2(11.1)	1(5.6)	17(94.5)	1(5.6)	0(0)
Scientist's observations of the same event will be the same because scientists think in the similar way.	1(5.6)	(2)11.1	15(83.4)	3(16.7)	0(0)	15(83.3)
Scientist's observations of the same event will be the same because observations are facts.	7 (38.9)	8(44.4)	3(16.7)	3(16.7)	1(5.6)	14(77.8)

Appendix Table 3 (Continued)

	Pre-instruction Questionnaire			Post- instruction Questionnaire		
Aspects of NOS	**SA and A**	**U**	**D and SD**	**SA and A**	**U**	**D and SD**
Change of Scientific Theories						
Scientific theories are subject to on-going testing and revision.	7(38.9)	4(22.2)	7(38.9)	1(5.6)	1(5.6)	16(88.9)
Scientific theories may be completely replaced by new theories when new evidence is found.	8(44.4)	4(22.2)	6(33.3)	16(88.9)	1(5.6)	1(5.6)
A new interpretation of data can change our present scientific knowledge.	11(61.1)	2(11.1)	5(27.8)	13(72.2)	2(11.1)	3(16.7)
Scientific theories based on accurate experimentation will not be changed.	8(44.4)	4(22.2)	6(33.3)	4(22.2)	0(0)	14(77.8)
Scientific Laws vs. Theories						
Scientific theories exist in the natural world and are discovered through scientific investigations.	13(72.2)	2(11.1)	3(16.7)	17(94.4)	1(5.6)	0(0)

Appendix Table 3 (Continued)

	Pre-instruction Questionnaire			Post-instruction Questionnaire		
Aspects of NOS	**SA and A**	**U**	**D and SD**	**SA and A**	**U**	**D and SD**
Scientific theories can change but scientific laws do not change.	14(77.8)	1(5.6)	3 (16.7)	9(50)	0(0)	9(50)
Scientific laws are theories that have been proven.	14(77.8	2(11.1)	2(11.1)	8(44.4)	0(0)	10(55.6)
Scientific theories explain scientific laws.	9(50)	3(16.7)	2(11.1)	15(83.3)	0(0)	3(16.7)
Social and cultural embeddedness						
Scientific research is not influenced by society and culture because scientists are trained to conduct “pure”, unbiased studies.	14(77.8)	2(11.1)	2(11.1)	9(50)	0(0)	9(50)
Cultural values and expectations determine <u>what</u> science is conducted and accepted.	7(38.9)	4(22.2)	7(38.9)	14(77.8)	0(0)	4(22.2)
Cultural values and expectations determine <u>how</u> science is conducted and	5(27.8)	4(22.2)	9(50)	13(72.2)	1(5.6)	4(22.2)

Appendix Table 3 (Continued)

	Pre-instruction Questionnaire			Pre-instruction Questionnaire		
Aspects of NOS	**SA and A**	**U**	**D and SD**	**SA and A**	**U**	**D and SD**
accepted.						
Science is not influenced by cultural and societal values because science is independent of society and culture.	13(72.2)	1(5.6)	4(22.2)	6(33.3)	1(5.6)	11(61.1)
Imagination and Creativity in Scientific investigation						
Scientists use their imagination and creativity when they collect data.	10(55.6)	0	2(11.1)	18(100)	0(0)	0(0)
Scientists use their imagination and creativity when they analyze and interpret data.	11(61.1)	6(33.3)	1(5.6)	18(100)	0(0)	0(0)
Scientists do not use their imagination and creativity because these conflict with their rational reasoning.	2(11.1)	5(27.8)	11(61.1)	1(5.6)	0(0)	17(94.4)
Scientists do not use their imagination and creativity because these can interfere with objectivity.	4(22.)	4(22.2)	10(55.6)	1(5.6)	0(0)	17(94.4)

Appendix Table 3 (Continued)

	Pre-instruction Questionnaire			Pre-instruction Questionnaire		
Aspects of NOS	**SA and A**	**U**	**D and SD**	**SA and A**	**U**	**D and SD**
Methods of Scientific Investigation						
Scientists use different types of methods to conduct scientific investigations.	9(50)	0	9(50)	11(61.1)	2(11.1)	5(27.8)
Scientists follow the same step-by-step scientific method.	4(22.2)	3(16.7)	11(61.1)	4(22.2)	1(5.6)	13(72.2)
When scientists use the scientific method correctly, their results are true and accurate.	5(27.8)	3(16.7)	10(55.6)	8(44.4)	0(0)	10(55.6)
Experiments are not the only means used in the development of scientific knowledge.	11(61.1)	2(11.1)	5(27.8)	13(72.2)	1(5.6)	4(22.2)
The Empirical Nature of scientific Knowledge						
Scientists make sufficient observations and measurements to reduce error and obtain reliable evidence.	12(66.7)	4(22.2)	2(11.1)	17(94.4)	1(5.6)	0(0)

Appendix Table 3 (Continued)

	Pre-instruction Questionnaire			**Pre-instruction Questionnaire**		
Aspects of NOS	**SA and A**	**U**	**D and SD**	**SA and A**	**U**	**D and SD**
Scientists use only direct evidence such as observational or experimental data to explain the natural world works.	7(38.9)	4(22.2)	7(38.9)	2(11.1)	1(5.6)	(15)83.3
Scientists do not use their imagination and creativity because these can interfere with	4(22.2)	4(22.2)	10(55.6)	1(5.6)	0(0)	17(94.4)
Scientists invent scientific knowledge, so it does not need observable evidence.	6(33.3)	2(11.1)	10(55.6)	2(11.1)	0(0)	0(0)

Appendix D

Students' Response from the Likert Scale from Phase 1

Appendix Table 4 Students' response from the Likert scale from phase 1

	SD and A	U	A and SA
Observations and Inferences			
Scientists' observations of the same event may be different because the scientists use earlier experience and knowledge may affect their observations.	50(12.9)	76(19.5)	263(67.6)
Scientists' observations of the same event will be the same because scientists think in the similar way.	242(62.2)	60(15.4)	87(22.4)
Scientists' observations of the same event will be the same because observations are facts.	95(24.4)	89(22.9)	205(52.7)
Scientists may make different interpretations based on the same observations.	41(10.5)	36(9.3)	312(80.2)
Change of Scientific Theories			
Scientific theories are subject to on-going testing and revision	43(11.1)	48(12.3)	298(76.6)
Scientific theories may be completely replaced by new theories when new evidence is found.	49(12.6)	51(13.1)	289(74.2)
A new interpretation of data can change our present scientific knowledge.	65(16.7)	83(21.3)	241(61.9)
Scientific theories based on accurate experimentation will not be changed	103(26.4)	78(20.5)	208(53.5)
Scientific Laws vs. Theories			
Scientific theories exist in the natural world and are discovered through scientific investigations.	309(79.4)	43(11.1)	37(9.5)
Scientific laws are theories that have been proven.	38(9.8)	59(15.2)	292(75.1)
Scientific theories explain scientific laws.	37(9.5)	71(18.3)	281(72.2)

Appendix Table 4 (Continued)

	SD and A	U	A and SA
Scientific theories can change but scientific laws do not change.	82(21.1)	85(21.9)	222(57.1)
Social and Cultural Influence on Science			
Scientific research is not influenced by society and culture because scientists are trained to conduct "pure", unbiased studies.	89(22.9)	81(20.8)	219(56.3)
Cultural values and expectations determine what science is conducted and accepted.	130(33.4)	116(29.8)	143(36.8)
Cultural values and expectations determine how science is conducted and accepted.	112(28.8)	135(34.7)	142(36.5)
Science is not influenced by cultural and societal values because science is independent of society and culture.	116(29.8)	43(11.1)	230(59.1)
Imagination and Creativity in Scientific Investigation			
Scientists use their imagination and creativity when they collect data.	52(13.4)	28(7.2)	309(79.4)
Scientists use their imagination and creativity when they analyze and interpret data.	49(12.6)	63(16.2)	277(71.2)
Scientists do **not** use their imagination and creativity because these conflict with their rational reasoning.	218(56)	93(23.9)	78(20.1)
Scientists do **not** use their imagination and creativity because these can interfere with objectivity.	194(49.9)	106(27.2)	89(22.9)

Appendix Table 4 (Continued)

	SD and A	U	A and SA
Methods of Scientific Investigation			
Scientists use different types of methods to conduct scientific investigations.	10(2.6)	13(3.3)	366(94.1)
Scientists follow the same step-by-step scientific method.	93(23.9)	108(27.8)	188(48.3)
When scientists use the scientific method correctly, their results are true and accurate.	37(9.5)	77(19.8)	275(70.7)
Experiments are not the only means used in the development of scientific knowledge.	87(22.4)	75(19.3)	227(58.4)
The Empirical Nature of scientific Knowledge			
Scientists make sufficient observations and measurements to reduce error and obtain reliable evidence.	35(62)	62(15.9)	292(75.1)
Among different scientific theories, the acceptance of scientific theory depends on experimental evidence.	43(40)	40(10.3)	306(78.7)
Scientists use only one direct evidence such as observational or experimental data to explain the natural world works.	110(28.3)	119(30.6)	160(41.1)
Scientists invent scientific knowledge, so it does not need observable evidence.	174(44.7)	129(33)	86(22.1)

Appendix E

Scoring Rubrics for Open-Ended Responses

Appendix Table 5 Scoring Rubrics for Open-Ended Responses

Aspects of NOS	Non- classifiable	Naïve views	Transitional views	Informed views
Observation and inference .	There is no response; students state that they do not know the answer; the response cannot be classified based on the rubric descriptions.	Scientists' observation and interpretation are the same because scientists are objective or observation are facts.	Scientists' observation and or interpretation may be different due to different ideas and knowledge without any example. Or scientists' observation and or interpretation may be different but fail to justify or give reason to support their statements or unrelated examples.	Scientists' observation and or interpretation may be different because of prior knowledge and personal perspectives or belief.
Tentativeness	There is no response; students state that they do not know the answer; the response cannot be classified based on the rubric descriptions.	Scientific theories do not change, if they based on accurate experiments or facts or the response includes misconception in	Scientific theories may change without any justification or if the students provides unrelated examples.	Scientific theories may change, due to the advancement in experimental technique, or new evidences are found

Appendix Table 5 (Continued)

Aspects of NOS	Non-classifiable	Naïve views	Transitional views	Informed views
Tentativeness		their views concerning nature of science or self.		when the existing evidence is reinterpreted.
Scientific theories Vs scientific laws.	There is no response; students state that they do not know the answer; the response cannot be classified based on the rubric descriptions.	There is no difference between scientific laws and scientific theories Or Scientific theories and scientific law do not do not change or The response which includes misconception in their views concerning nature of science or self-contradicting statements.	Scientists find theories or laws in nature. Or The students give valid example of scientific laws and scientific theories without explanation.	Scientific Theories and Scientific laws are kinds of scientific knowledge, both are subject to change Or Scientific theories explanation of natural phenomena or scientific law.
Social and culture influence on science	There is no response; students state that they do not know the answer; the	The response which includes misconception in their views concerning	Culture and society will influence or determine what and how science is conducted, or	Scientists' work is influenced by the societal and cultural values and it determines what and how science is

Appendix Table 5 (Continued)

Aspects of NOS	Non- classifiable	Naïve views	Transitional views	Informed views
Social and culture embeddedness	response cannot be based on the rubric descriptions.	nature of science or self-contradicting statements.	accepted. Or Students simply state that science is being influenced by social and cultural values without any explanation.	conducted and accepted.
Creativity and imagination	There is no response; students state that they do not know the answer; the response cannot be classified based on the rubric descriptions.	Scientists do not use imagination and creativity. Or The response which includes misconception in their views concerning nature of science or self-contradicting statements.	Scientists use imagination and creativity and if the students mention that only in certain part of investigation. For example during designing experiment or solving problems. Or without examples.	Scientists use imagination and creativity and if the students mention it scientist use imagination and creativity throughout the scientific investigation.

Appendix Table 5 (Continued)

Aspects of NOS	Non-classifiable	Naïve views	Transitional views	Informed views
Methods of scientific investigation .	If there is no response; students state that they do not know the answer; the response cannot be classified based on the rubric descriptions.	If there is a single, universal or step –by-step scientific method that should be used Or The response which includes misconception in their views concerning nature of science or self-contradicting statements.	Scientists may use different methods, but their result must be confirmed by experiments. Or Students just say different method without any justification.	If there is no single or universal that all scientists must. Depending upon the nature of the work scientists use a variety of methods such as observation, experimentation, library investigation, photography etc.
Empirical nature of scientific knowledge	If there is no response; students state that they do not know the answer; the response cannot be classified based on the rubric descriptions.	The response which includes misconception in their views concerning nature of science or self-contradicting statements.	If the students just states body of knowledge. (Concepts, facts, and theories) or process part. Or do not differentiate between science and religion	Science is discipline to address question about natural world, the role of science is providing explanations for the natural phenomena, and empirical evidence plays in science that separate science from other disciplines.

Source: adapted and adopted from (Liang *et al*., 2009 and Lederman *et al*., 2002)

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