

# Enhancing Bhutanese Students' Views of the Nature of Science in Matter and its Composition and Study of Gas Laws through an Explicit and Reflective Approach

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## ABSTRACT

This study investigated the development of Bhutanese students' views of the nature of science (NOS) as they engaged in an explicit and reflective approach. Seven aspects of NOS were integrated into the chemistry content in two learning units titled "matter and its composition" and "study of gas laws" over a time span of 6 weeks in a 9<sup>th</sup> Grade class. This study employed mixed method approaches which included the use of a questionnaire, semi-structured interviews, classroom observations, and a review of students' journals, and assignments. Data were analyzed for established patterns and themes. Students' views of the NOS in pre-instruction and post-instruction were categorized as naïve, transitional, or informed. The results indicated that at the end of the intervention, students' views of the NOS had improved. It was seen that NOS-specific pedagogical knowledge and subject knowledge played an important role in the teacher's ability to enhance students' views of the NOS.

**KEY WORDS:** Bhutan; chemistry; explicit and reflective approach; inquiry; nature of science

## INTRODUCTION

For half a century, an understanding of the nature of science (NOS) has been emphasized in both general science education and chemistry education as it is a key component of scientific literacy (Lederman et al., 1998; McComas and Olson, 1998; NGSS Lead States, 2013). An individual with an adequate understanding of NOS is considered to be scientifically literate and 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 chief purposes of teaching NOS to students are to motivate and encourage them to understand the nature and relationship between science and technology, to encourage students to investigate the history and origin of scientific facts and ideas, and to enable them to appreciate the roles and responsibilities of science and technology in improving personal lives and the society. Understanding of NOS enhances students' ability to evaluate critically scientific inventions and their benefits, as well as to help themselves in the debates surrounding both current and future scientific issues. Furthermore, an understanding of NOS enhances the learning of science content and the understanding of science and develops positive and scientific attitudes toward learning science (Bell et al., 2000; Clough and Olson, 2012). Therefore, helping students to develop an adequate understanding of NOS has become a central goal of science instruction in many countries

(see, for example, Department of Curriculum Research and Development, 2011; NGSS Lead States, 2013; New Zealand Ministry of Education, 2012).

Over the past years, many empirical studies have found that students have inadequate and inappropriate views of NOS (Bell et al., 2003; Rubba and Anderson, 1978). Science educators and researchers have investigated ways to shift students' NOS naïve views toward more informed views. Most of the studies argued that an explicit and reflective approach of addressing NOS was the most appropriate way to present science learning activities (Abd-El-Khalick and Lederman, 2000; Yacoubian and BouJaoude, 2010). In an explicit and reflective approach, the aspects of NOS are mentioned in the objectives of the lesson, and the students are provided an opportunity to discuss the aspects of NOS. On the other hand, with an implicit approach, there is an assumption that the students will learn NOS somehow automatically as students engage in inquiry activities while learning science.

Even though many researchers are convinced that an explicit and reflective approach is appropriate for enhancing students' NOS, few studies have been conducted integrating NOS through this approach specifically in chemistry concepts. NOS should be taught by integrating it with content for promoting long-term retention of NOS concepts (Bell et al., 2011). Teaching NOS with specific chemistry content is challenging. Knowing pedagogy is not enough, but rather there is a need to know how to teach a particular chemistry topic relevant to NOS

aspects, so-called pedagogical content knowledge for teaching NOS (PCK for teaching NOS) (Faikhamta, 2013; Hanuscin et al., 2011). If one view NOS as content and targets aspects of NOS as topics to be taught, it is important to be familiar with topic-specific knowledge relevant to NOS aspects. If one wishes to teach, for example, the NOS aspect of laws and theories to specific groups of students in a particular context, the demands of teaching and learning this aspect may be different from the demands of teaching about the NOS aspect of tentativeness. Teachers are required not only to understand NOS but also must know how to teach NOS in particular chemistry topics to a particular group of students (Faikhamta, 2013; Hanuscin et al., 2011).

To respond to this concern, it is useful to investigate how to teach particular chemistry topics (e.g., matter and its compositions) when those topics are integrated with NOS. The present study intended to develop students' views of NOS through an explicit and reflective inquiry approach. This study's specific research question was: How does an explicit and reflective inquiry approach influence Grade 9 Bhutanese students' views of NOS within the context of a unit on matter and its composition?

## CONCEPTUAL FRAMEWORK NOS

There are many debates going on among science philosophers, science historians, and science sociologists about the specific and precise definition of NOS. However, there is an acceptable level of generalization regarding some aspects of NOS, which are less controversial. Lederman (2007) 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 has been the object of systematic educational research for approximately 50 years (p. 836).

Some of these aspects of NOS are accessible to K-12 and are applicable in daily life and so can help students to make connections between science knowledge and scientific claims. The general aspects that create an agreement among historians, philosophers, and science educators and that have been emphasized in many reforms and empirical studies are as follows: Scientific knowledge is tentative, empirically based, subjective (theory-laden), partly the product of human inference, imagination, and creativity, and socially, and culturally embedded (Lederman et al., 2002). Two additional important aspects are the distinction between observations and inferences, the functions of and relationships between scientific theories and laws.

Science educators address similar aspects but use different terms to describe the concepts based on their beliefs. For instance, Lederman et al. (2002) use "scientific knowledge is theory laden" whereas Liang et al. (2008) use "subjectivity and objectivity in science." For another concept, scientific method,

Lederman et al. (2002) use "myth of scientific method," but Liang et al. (2008) use "scientific method," while McComas (2004) uses "knowledge production in science including many common features and shared habits of minds" (no single step-by-step scientific methods). Although McComas (2004) has nine aspects of NOS, they correlate with other educators. For instance, social influences on science and technology influence each other. The historical, cultural, and social influence on science are kept as different aspects, but Lederman et al. (2002) and Liang et al. (2008) have merged these together and termed them "social and cultural embeddedness."

Science is not a study of mere facts and figures, investigations, observations, the collection of data, and its interpretation. It is an endeavor designed to explore the natural world, which includes beliefs, curiosity, imagination, creativity, sets of methods, societal values embedded in it, and processes through which knowledge is produced or understands reality. Science is a body of knowledge, methods, and ways of knowing. Body of knowledge refers to the products of science, methods refer to various ways to obtain scientific knowledge, and a way of knowing deals with scientific 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 NOS, which is appropriate in the context of our study of 9<sup>th</sup> Grade students in Bhutan. These aspects are tentativeness (subject to change), empirical basis, imagination, creativity (involves the invention of explanations), methods of scientific investigation, distinction between observation and inference, and distinction between law and theory.

### Teaching the NOS

Research has consistently shown that the implicit NOS inquiry-oriented curricula and research interventions were ineffective in enhancing students' views of NOS (Khishfe and Abd-El-Khalick, 2002). The implicit approach emphasizes doing science with the assumption that students learn NOS through scientific investigations and that doing science itself will help students develop more accurate understandings of the nature of scientific inquiry and knowledge (Bell et al., 2011). For instance, when students are involved in inquiry-oriented activities and are using science process skills, they are expected to develop sufficient understanding of NOS (Schwartz et al., 2004).

Many science educators have noted that an explicit and reflective instructional approach is an effective way to enhance students' understanding of NOS (Akerson et al., 2002). Bell et al. (2011) stated that "the explicit approach seeks to intentionally draw students' attention to targeted aspects of the NOS through discussion, reflection, and specific questioning in the context of activities, investigations, historical examples, and analogies" (p. 415). Further, Abd-El-Khalick and Lederman (2000) pointed out that understanding

NOS should be undertaken as cognitive learning that should be taught explicitly with proper planning, keeping in mind the anticipated learning outcomes expected at the end of the lesson. In explicit and reflective approach, students have opportunities to reflect on the aspects of NOS that have been emphasized in the context of that particular science-based activity or the broader scientific content (Khishfe and Abd-El-Khalick, 2002).

## METHODOLOGY

### Context of the Study

Participants were Bhutanese students from a secondary school comprised 1100 students in total. This school had three classes for the 9<sup>th</sup> Grade with a total of 55 students evenly divided between the classes. From these three classes, one was randomly selected to participate in this study. The reason for choosing this particular school was for its convenience and proximity since the first author had worked there as a teacher in this school for 9 years and taught these students when they were in the lower grades. All these factors allowed the researcher to understand better the degree to which each student understood the NOS. In this study, the first author was the teacher who integrated NOS into the chemistry course's instructional content in the two units: Matter and its composition and study of gas laws.

### Data Collection

Multiple data sources were used in this study. Questionnaires, students' journals, observations, and teachers' self-reflection were collected and analyzed. To ensure credibility in this study, data were collected from these multiple sources and were triangulated. Prolonged engagement was conducted, in which all the classroom teaching was recorded and observed in each period to observe the development of students' understanding of NOS. As stated, the first author had worked in the same school for 9 years, which helped provide a better understanding of the development of the students' understanding of NOS during the intervention.

A combination of 28 Likert-type items and 7 open-ended questions were used as a research instrument to explore the students' view of NOS. The Likert-type items were adapted from "students understanding scientific inquiry" (SUSSI) (Liang et al., 2008) while the open-ended questions were adopted from Lederman et al. (2002) and Park et al. (2014). The original version of SUSSI 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 in scientific investigations, and methodology of scientific investigation. Each concept has four closed-ended responses, which range from "strongly disagree" to "strongly agree" followed by open-ended response options. Students were asked to select responses in the Likert format and then explain their actual understanding of NOS and scientific inquiry with examples (Liang et al., 2008). To ensure the content validity of the instrument, three experts including the original developer

of the SUSSI and two science teachers who currently teach Grade 9 students in Bhutan examined the items. To ensure the reliability of the instrument, a pilot study was conducted with students from two schools in Bhutan. Cronbach's alpha value used to evaluate internal reliability for the whole instrument was 0.85 (Das et al., 2017).

In addition, there were other data sources such as student journals, classroom observations, and semi-structured interviews. Students were instructed to write in a reflective journal once a week. For classroom observations, the teaching in the class was recorded using videotape. Semi-structured interviews were conducted at the end of the pre-test and post-test to further probe the students' understanding of NOS, especially for the students who wrote unclear answers. All interviews were audio taped.

### Data Analysis

The data collected from the pre-instruction questionnaire were analyzed in four steps. In the first step, the Likert-type items were sorted into three categories, i.e., naïve, transitional, and informed views, using the rubric adapted from Liang et al. (2008). A code of 1, 2, or 3 was given to each theme. The students' responses were categorized as naïve views (1) if none of the four responses scored  $<3$ , transitional (2), if one or more than one (but not all) of the four responses are either more equal to or  $<3$ , and informed views (3) if all of the four responses received a score of more than three. Percentages in each category (naïve, transitional, and informed views) were calculated.

In the second step, the students' responses to the open-ended questions were classified into four categories (non-classifiable, naïve, transitional, and informed views) based on the rubrics developed by Lederman et al. (2002). Students' open responses were classified into four categories based on Liang et al. (2008), thus 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 "don't know," or if the response was written did not answer that particular question, the answer was classified as non-classifiable. Responses that showed misconceptions and self-contradictory statements were classified as naïve. If the students showed partially informed views without any justification, or if the students provided unrelated examples, these were classified as transitional views. If the students' response was consistent with a contemporary position on science, it was classified as an informed view. Interviews were transcribed to follow-up on open-ended responses that were ambiguous. Then, percentages in each category were calculated.

In the third step, all of the open-ended responses were reread to come up with patterns and themes for each aspect of NOS. To ensure the data analysis reliability of the data collected, the first author first analyzed all the data independently, and all the analyzed data were reviewed by the second and third authors. Differences in the authors' interpretations were resolved through further discussions until reaching consensus.

In the fourth step, the video records from the classroom observations of each period were transcribed word by word to review the teacher's teaching. The dialogue in which aspects of NOS were discussed explicitly was extracted to serve as an evidence to support the claim that an explicit and reflective inquiry approach can enhance Bhutanese students' understanding of NOS.

## FINDINGS

Table 1 shows that before the intervention, the majority of the students held inadequate views on all the targeted aspects of NOS. After the intervention, the change was observed in students' views in all aspects of NOS. The details of student development of NOS and their learning were as follows.

### Observation and Inference

From the pre-instruction questionnaire responses in the Likert-type items, the majority (94.4%) of the students held transitional views in this NOS aspect according to the application of the scoring rubrics. Similarly, in the open-ended responses, 83.3% of the students held transitional views. Overall, only a minority of the students held informed views both in the Likert-type items and in the open-ended responses. Coming to the individual sub-scales, interestingly the majority (83.3%) believed that scientists' observation of the same events may be different because the scientists use of earlier experience and knowledge may affect their observations, which indicated that the students are aware of the theory-laden aspect of NOS. Similarly, the students who held transitional views believed the scientists' observations and interpretations are different because different scientists have different thinking and ideas. For instance, one of the students' responses was:

I think scientist's 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).

After the intervention, there was substantial improvement in students' understanding of this NOS aspect. The students with naïve views had developed either transitional or informed views, and transitional students had developed informed views. There were two lessons that explicitly discussed observation and inference aspects of NOS.

To develop students' views on the aspects of observation and inference in NOS from naïve to informed, a decontextualized activity (mystery box activity) and "phases of states of matter," were implemented. Before the teaching "phases of states of matter," the teacher arranged seven stations that showed different phenomenon: Melting, evaporation, sublimation, condensation, freezing, and vaporization. Students rotated among stations, where the students had to investigate the phase displayed at each station. Students were asked to go to each station and observe and infer the natural phenomenon that occurred there. In addition, students were to state where it started (solid, liquid, or gas) and ended (solid, liquid, or gas) and determine whether the substance was absorbing or releasing heat. Students were asked to spend only 5 min per station to record their observations, to discuss which two states and which phase change they were observing, and finally to explain their rationale.

Once the students completed their observations, an explicit-reflective discussion was carried out. In the discussion, the students were asked to reflect on what they observed and inferred during the phenomena occurring in each phase change that took place in each station. An excerpt from the conversation and responses with some of the students during the explicit-reflective discussion was:

- T: On Station 2, Watch glass on beaker of water on a hotplate, what did you observe?
- S(4): Water boiling.
- S(2): I observed there were tiny droplets of water on the surface of watch glass.
- S (5): Water vapor is rising.
- T: What happens to the water vapor? What happens 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 it is condensation, and we also have 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 a conclusion using prior knowledge.

**Table 1: Percentage of Likert-type items responses in the pre-instruction and post-instruction (n=18)**

NOS aspects	Pre-instruction			Post instruction		
	Naïve	Transitional	Informed	Naïve	Transitional	Informed
Observation and inference	0 (0)	17 (94.6)	1 (5.3)	0 (0)	6 (33.3)	12 (66.7)
Change of scientific knowledge	5 (26.3)	10 (52.6)	3 (15.8)	0 (0)	9 (50)	9 (50)
Law versus theory	9 (50)	9 (50)	0 (0)	1 (5.6)	9 (50)	8 (44.4)
Social and cultural influence on science	8 (44.4)	10 (55.6)	0 (0)	0 (0)	10 (55.6)	8 (44.4)
Imagination and creativity	1 (5.6)	9 (50)	8 (44.4)	0 (0)	2 (11.1)	16 (88.9)
Methods of scientist investigation	1 (5.6)	17 (94.4)	0 (0)	0 (0)	10 (55.6)	8 (44.4)
The empirical nature of scientific knowledge	1 (5.6)	17 (94.4)	0 (0)	1 (5.6)	6 (33.3)	11 (61.1)

- T: So how your work is similar to scientists' work?
- S: We use prior knowledge, make predictions and observations, have hypotheses, infer, and communicate.

The post-instruction questionnaire asked, "do you think all scientist observations and interpretations are the same or different? With examples, explain why you think scientists' observations and interpretations are the same or different." From the responses to this question, substantial development of students' views in this aspect was noted in the open-ended responses. The percentage of students who held informed views changed from 9.7% to 66.7%. The students with the informed views noted that scientists' observations and inferences are different because of their different thinking, prior knowledge and the scientists' background that showed the theory-laden aspect of the NOS.

### Tentativeness

Altogether, 15.8% of the students held informed views in this aspect of NOS in the pre-instruction responses of the Likert-type items, in the open-ended responses, interestingly, none of the students held informed views. Examining the individual subscale, only 38.9% of the students believed that scientific theories are subject to on-going testing and revision, and 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 students held naïve views. Many of the students who held naïve views believed that scientific knowledge is not going to change because scientific theories or knowledge is strongly proven with many facts. An example of the students' responses was:

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

To develop students' views on the tentativeness aspect of NOS, two topics were designed explicitly to draw students' attention to it by teaching it with the topics matter and its composition and law of conservation of mass. In the first topic, the students learned about the timeline of ideas about the composition of matter held by various philosophers and scientists 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 was to pick one of the philosophers or scientists and then read the history about the origin of their ideas about the composition of matter and discuss those ideas. The groups were asked to prepare a summary chart and then report to rest of the class. After the presentation, students were to trace the changes in the ideas about the composition of matter.

The development of students' understanding of this NOS aspect seemed to be considerably higher compared to other aspects in the pre-questionnaire. On examination of individual Likert item responses, only 38.9% of the students believed that "scientific theories are subject to on-going testing and revision" before

the intervention. However, after the intervention, it changed to 88.9%. Similarly, 44.4% of students in the sub-Likert items disagreed that scientific theories based on accurate experimentation will not be changed before the intervention, and after the intervention, 66.7% of the students disagreed with this statement.

### The Distinction between Scientific Laws and Theories

Before the intervention, none of the students held informed views of scientific theories and scientific laws, both in Likert and open-ended responses. Coming to the individual subscale of Likert-type items, the majority of the students (77.8%) believed that "scientific laws are theories that have been proven" in the subscale response in the Likert-type items. 77% of the students believed that "the scientific theory will change, but the scientific law will not change." In the open-ended responses, interestingly, some students viewed scientific laws as a rule that a scientist would follow during scientific research. For example, one of the students stated:

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, this student 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). The students seemed to have made this misinterpretation because of the language.

To develop students' views on the scientific theories and scientific laws, a guided inquiry lesson was used to teach the Law of Conservation of Mass, Boyle's Law, and Charles' Law. For example, the lesson of Boyle's Law, the teacher began asking students to predict what happened with the size of balloon inserted inside an airtight syringe when the plunger is pushed, and why it happened like that. The students were allowed to think and design an investigation to see how the pressure is related to the volume. Students interpreted their data in a graphical representation to show the relationship between volume and pressure and presented this 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 the inversely proportional relationship between the two. In addition, a mathematical equation that described the relationship between pressure and volume was explained to the students. Students were motivated to explain why pressure of gas is increasing and the volume is decreasing. The teacher instructed the students to write their postulate of the kinetic theory of gas on the board and then further discussed the theory. After students understood the kinetic molecular theory, the teacher asked the students what "scientific theory" means. The students were able to distinguish between scientific law and scientific theory based on its function and no longer held the belief that scientific laws are theories that have been

proven. Students seemed to have developed their understanding of scientific law and scientific theory.

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

### Social and Cultural Embeddedness

The responses from both the Likert-type and the open-ended pre-instruction questionnaire showed that none of the students held informed views of NOS. Interestingly, the individual subscale revealed that 77.4% of the students believed that "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 that "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 (88.9%) of the students held naïve views before the intervention. Some of these students believed that scientific knowledge and research deals with scientific truth, and it is not affected by culture and society. The work of science 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 society and culture:

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

The social and cultural embeddedness aspect of NOS was integrated in the topic of matter and its composition. Each group of students was given one philosopher's or scientist's ideas about the composition of matter. Students were encouraged to discuss questions concerning how the knowledge of the composition of matter had changed over the past and how social and cultural values influence scientific knowledge.

The development of students' views from naïve to informed was observed though this was less substantial compared to other aspects of NOS. Before the intervention, 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 from the open-ended response. A representative student's response from the informed views was:

Yes, social and cultural values decide 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 minimal, as only 27.8% of the students changed from naïve to informed views after the intervention. The students who were categorized as 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

Before the intervention, about 50% of the students held transitional views, and 44.4% held informed views as indicated by the Likert-type items. When the individual subscale was 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." Another 61.1% disagreed on the statement, "scientists do not use their imagination and creativity because these can interfere with objectivity." In the open-ended response, the majority (about 88.9%) of the students held transitional views. These students saw that scientists use their creativity and imagination in new discoveries and invention; moreover, many students gave examples from the history of science, which they might have learned from textbooks or heard it from their teachers. The majority of the students failed to recognize that creativity was involved in the process of science in the open response, for example:

Yes, I think scientists use creativity and imagination during investigation/experimentation because if scientist 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).

To develop students' views from naïve to informed views on the creativity and imagination aspect of NOS, two lessons were taught. The first one used the decontextualized activity (mystery box) in the composition of matter and the second was in the laws of conservation of mass. This activity focused to teach and connect how scientists come up with models that help them to explain phenomena of things that cannot be seen directly - either with the naked eye or with the help of instruments due to extremely small size (such as atoms and organelles) or very long distance (such as other galaxies and stars). Students were provided with a magnet and a stethoscope along with some questions to guide them, and they 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 the stethoscope and using the magnets to find out whether the object inside the box was metallic. Students drew their interpretations and presented them to the whole class. This activity helped students to understand that scientists do use creativity and imagination during the investigation. In addition, the teacher further emphasized that indirect observations in science are often made when direct observation is insufficient for determining the unknown cases, like when a scientist cannot cut the Earth or Sun in half, or see inside an atom. In such cases, a scientist must rely on indirect observation and

inference; therefore, imagination and creativity are used to see the unseen object.

The most remarkable development noticed at the end of the intervention was in this aspect of NOS when compared with the rest of the aspects. At the beginning of the intervention, only 44.4% of the students 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, 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 inventions but also throughout the scientific investigation.

### 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-types items (94.4%) and open-ended responses (88.9%). When individual Likert-type items were examined, 61.1% of the students disagreed on the statement, “scientists follow the same step-by-step method,” and “when scientists use the scientific method correctly, their results 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 mention examples of methods that scientists use. See for an example:

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).

Before the lessons, a majority of the students held transitional views, and none of the students held informed views as per students' responses from the open-ended and Likert-type items of the pre-instruction questionnaire. The students with transitional views knew that scientists used different types of methods but did not deeply understand what they are. To enhance students' views from naïve to transitional or to informed views, two lessons were designed.

To ensure that students understand the use of diverse methods during the scientific investigation, a lesson on soda and candy was adapted and adopted from (Bell, 2008) to teach students the steps in the scientific method. The teacher began the lesson by probing the students' prior knowledge about the experiment. Students referred to an experiment as a tool for proving scientific knowledge. Further, the teacher probed students' knowledge about a hypothesis, variables, and a controlled experiment; unfortunately, students were not able to answer. The teacher then explained the meaning of an experiment and the various steps involved in the scientific method. Once the students understood the literal meaning of terms such as experiment, hypothesis, dependent and independent variables, and controlled experiment, the teacher let the students predict what would happen when the Mentos candy was dropped in the Diet Coke. The teacher demonstrated the Mentos candy

phenomenon. During this activity, students were also asked to identify each step during the experiment. An explicit-reflective discussion was led by the teacher to draw students' attention to using diverse methods in science.

The response from the Likert-type items and open-ended responses from the post-instruction questionnaire showed that there was less substantial development of students' views observed in this aspect. Before the intervention, only 5.6% of the students, held informed views and at the end of the intervention 7 of the students (38.9%) held informed views. Regarding the individual Likert-type items, there was no development seen, especially in two items. Before 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.

### Empirical Nature of Scientific Knowledge

In answer to, “what is science?” and “what makes science different from other disciplines of inquiry (for example, religion, philosophy)?” A majority of the students held transitional views both in the Likert and open-ended responses before the intervention. In the Likert, about 94.4% of the students held transitional views. On closer examination of the sub-scale items, 66.7% believed that “scientists make sufficient observation and measurement to reduce error and obtain reliable evidence.” In another Likert sub-scale item, 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, the products of science knowledge and science that exists around them. A majority of the students perceived science as the study of living and non-living things and the environment around them but failed to mention that scientific knowledge is based on empirical evidence supported by observation and inference, before the intervention.

To develop students' understanding of this aspect of NOS, students' attention was drawn to it explicitly in the lesson of motion in the liquid. The lesson started with an activity that demonstrated the motion of liquids. A 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 particles in their notebook. Then, the teacher posed questions: “Is the speed of water molecules different in hot water and cold water? What can we do to find out?” Students worked in groups to design an experiment to investigate the speed of molecules in hot water and a cold medium. Students were also reminded to keep in mind the variable that they are going to keep the same, for example, the same amount of hot and cold water, the same amount of coloring material, and the same time you drop the ink in the beaker were to be noted. After students completed their designs, the teacher ensured the safety of the experiments. At this point, the importance of revising and modifying the procedure is important for the scientists to reduce error. The teacher tried to connect students' work with the work of scientists when they want to explain an event. Scientists

connect observations, scientific concepts, and principles in a reasonable way to make sense of the observations. When a 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. At the beginning, much confusion created chaos. Students were not able to design their experiments.

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. In the Likert-type items, 61.1% of the students showed informed views. Similarly, in the open-ended post-questionnaire, the percentage of students who developed their understanding to informed views increased from 5.6% to 66.7% after the intervention. 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. A majority of the students viewed science as a body of knowledge or the study of the natural phenomena from which scientific knowledge is generated. Furthermore, they believed that science demands empirical evidence.

## DISCUSSIONS, CONCLUSIONS, AND IMPLICATIONS

This study contributes to a better understanding of how students develop their understanding of NOS in a specific chemistry topic. By examining and enhancing 9<sup>th</sup> Grade students’ views of NOS through integration of the aspects of NOS in two units: Matter and its composition and study of gas law through an explicit-reflective approach, this study indicated that with proper lesson design and explicit focus on NOS students’ views can change from naïve to transitional or informed and from transitional to informed views in all aspects of NOS. This result is consistent with other studies (Bell et al., 2003; Khishfe and Lederman, 2006) which supported the idea that an explicit and reflective approach when teaching NOS improves students’ and teachers’ views of NOS. However, the development in all the aspects of NOS was not parallel, as 6-week duration was likely not long enough to develop students’ ideas into fully informed responses as argued by Faikhamta (2013). For instance, some aspects such as creativity and imagination, observation and inference, and the empirical nature of scientific knowledge showed a substantial gain. However, the development of students’ views about the social and cultural embeddedness aspects of NOS was less substantial. The reason could be the fact that this aspect was integrated only in one lesson due to the nature of the content. This indicated that the development of students’ views of NOS depends on both the nature of instruction and quantity of the instruction that has been devoted to that particular aspect, as pointed by Brickhouse et al. (2000).

As mentioned, there were variations in the development of the students’ views in each aspect of NOS. For instance, a substantial development was noted in students’

views on tentativeness, observation, and inference, and creativity and imagination aspects of NOS after these were introduced with a decontextualized activity and followed by inquiry approach. The responses from the pre-instruction questionnaire indicated 5.6% of the students held informed views, and the post-instruction questionnaire indicated 66.7% of the students held informed views, which showed a substantial development in students’ views on the creativity and imagination aspect of NOS. Similarly, regarding tentativeness and observation and inference, a decontextualized activity (mystery box activity) was introduced in teaching this aspect of NOS. Clough (2006) pointed that explicit decontextualized NOS instruction has a role to 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.

Unlike other countries, in the pre-instruction questionnaire responses, the majority of the Bhutanese students believed that scientists use different methods during the scientific investigation, but these students were not able to say what different types of methods were involved. Similarly, during the intervention, when students were asked about the various steps involved in the scientific method, they were unaware of the steps involved. Students knew only about the experiments. This could be because usually in Grades 7 and 8 the students learn integrated science, and the teaching is mostly teacher-led, and the students rarely get an opportunity to be engaged in the scientific investigation. However, after the intervention, many students held informed views.

Interestingly, after the intervention, only 27.8% of the students held informed views in the social and cultural embeddedness aspect of NOS. The majority of the students believed that science is independent of society. It seems that the social and cultural embeddedness aspects of NOS are difficult to teach to the middle, secondary school students. The underlying fact is that Bhutan has unique traditions and culture, and Bhutanese value these above everything. Since all Bhutanese are influenced deeply by this nationalistic view of life, students take culture very seriously in a protectionist sense which could have made the students perceive science as independent from social and cultural values. In addition, Bhutan has rich and unique cultural heritage. Buddhism is a central part of community life and has had a strong influence on the culture and attitude of the Bhutanese people. In Bhutanese’s views, these traditional beliefs and religion are useful for the preservation of the natural environment. Hence, when science and modern technology comes to Bhutanese ways of life, it has been seen as an external and physical entity. Further research should examine how to develop students’ understanding of NOS in the context of different cultures. This research will contribute the knowledge of student learning of NOS in particular context and culture.

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