Pre-service Science Teachers' Conceptions of the Nature of Science

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Abstract

Understanding the Nature of science is a crucial part of scientific literacy that helps students develop ideas about science and make informed decisions. Science teachers' knowledge of the Nature of science is essential to enhancing students' understanding. This study examined 50 pre-service science teachers' conceptions of the Nature of science. The data collected by administering the Understanding the Nature of science questionnaire was analysed using descriptive statistics and a one-way analysis of variance test. The findings revealed that pre-service science teachers have uninformed conceptions about the Nature of science, particularly in the tenets of scientific methods, scientific theories and laws, scientific knowledge, and scientific enterprise. There was no statistically significant difference in the level of Nature of science conceptions based on their specialisation ($F [2, 47] = .251$). Future research is encouraged to explore the implications of teachers' conceptions of the Nature of science on students' understanding, employing a multi-method approach.

Keywords: Conception, nature of science, scientific literacy, pre-service, science teachers

Introduction

One of the fundamental purposes of science education is to build a scientifically literate society by providing informed conceptions of science (Bayir et al., 2014). An informed conception of science enhances individuals' ability to make informed decisions and choices related to the scientific and technological issues in our daily lives (Irez, 2006; Karisan & Cebesoy, 2018; Oh, 2017). One approach to achieving scientific literacy is by understanding the Nature of science (NOS) (McDonald, 2010).

Nature of science describes what science is, the way science works, and how science and societies are impacted by one another (Bell et al., 2016; McComas & Clough, 2020). If citizens have a thorough understanding of the attributes and the construction of scientific knowledge, they will be better equipped to comprehend pseudo-scientific claims and apply scientific knowledge appropriately in solving everyday issues (Bell & Lederman, 2003; Karisan & Cebesoy, 2018; Thao-Do & Yuenyong, 2015). The inclusion of NOS in science curricula would help students understand science as a process of scientific enquiry, allowing them to make well-informed scientific decisions and become skilled science consumers (Bell et al., 2011; Bell et al., 2016; McComas & Clough, 2020).

The development of an accurate understanding of NOS has been prioritised in science curriculum revisions around the world (Bell et al., 2011). It is crucial to deliver NOS effectively to science learners to reinforce science as a rational way of knowing (Backhus & Thompson, 2017). Teachers' thorough conception of NOS allows them to model appropriate scientific attitudes and behaviours (Buaraphan, 2011) and, in turn, enhances students' conceptions and overall achievement in science (Wahbeh & Abd-El-Khalick, 2013; Waters-Adams, 2006). However, studies have consistently revealed that both pre-service and in-service science teachers hold naïve conceptions of NOS (Bayir et al., 2014; Irez, 2006; Kite et al., 2020; Wahbeh & Abd-EI-Khalick, 2013; Wangdi et al., 2019). Consequently, there is a risk that these teachers may instill misconceptions about the NOS in students in the classroom (Jain et al., 2013). It is, thus, critical to delve deeper into science teachers' perceptions of NOS, understand the implications of NOS instructions, and enhance science teachers' knowledge towards comprehending NOS (Bell et al., 2011; Karisan & Cebesoy, 2018; Waters-Adams, 2006).

This study is concerned with examining pre-service science teachers' conceptions of NOS. Understanding NOS is important both for pre-service science teachers as well as for in-service science teachers. Extant literature indicates that pre-service science teachers hold uninformed conceptions of NOS (Akerson et al., 2019; Demirdogen et al., 2015; Jain et al., 2013; Karisan & Cebesoy, 2018; Reiners et al., 2017). Such issues, if unaddressed, on the onset of teacher preparation programmes will encourage newly graduated science teachers to enter the profession with unexamined and uninformed views of NOS (Irez, 2006). Such practice would gradually impede the capacity of the schools striving to produce scientifically literate individuals who can lead a productive life (Buaraphan, 2011; Wan et al., 2013). There are limited studies on the status of pre-service science teachers' conceptions of NOS in the Bhutanese context. To date, only one research has investigated Bhutanese in-service science teachers' perceptions of NOS (see Wangdi et al., 2019). Wangdi et al. (2019) observed that most in-service science teachers have uninformed conceptions of NOS and recommended similar investigations targeting pre-service science teachers. Our research extends this study of NOS and teachers (e.g., Wangdi et al., 2019) by investigating pre-service science teachers' conceptions of NOS.

The aim of the study was operationalised by two research questions:

RQ. 1 What are pre-service science teachers' conceptions of the Nature of science?

RQ. 2 What is the relationship between pre-service science teachers' conceptions of the Nature of science?

The Nature of Science

The concepts and definitions of NOS have been long discussed; however, no precise conclusion has been drawn on its universal definition (McDonald, 2010; Wangdi et al., 2019). Since its characteristics remain general and diversified, no single or universal conception explains the whole set of scientific knowledge and enterprises (Chaiyabang & Thathong, 2014; Wangdi et al., 2019). Conversely, NOS is commonly perceived as the theoretical knowledge of science that entails the logical and evidence-based development of scientific knowledge, its values and beliefs inherent to scientific understanding (Bell & Lederman, 2003; Buaraphan, 2011; McDonald, 2010) including how science and society influence one another (Demirdogen et al., 2015; Thao-Do & Yuenyong, 2015).

Despite several conflicting views of NOS, some of the commonly discussed tenets of NOS include (1) the tentative NOS, (2) the empirical NOS, (3) the relationship between scientific theories and laws, (4) the subjectivity, (5) the nature of scientific methods, (6) the nature of observations and inferences in science, (7) the creativity and imagination in sciences, and (8) the social and cultural embeddedness of science (Akerson et al., 2019; Irez, 2006; Jain et al., 2013; McComas, 2020). These tenets of NOS are adopted and aligned based on the scope of one's study.

Conceptualising the Nature of Science for this Study

Nature of Science in this study was conceptualised based on five tenets: (1) the nature of scientific knowledge, (2) the nature of scientific theories and laws, (3) the nature of scientific methods, (4) the nature of scientists' works, and (5) the nature of scientific enterprises. There were mainly two reasons for considering these five tenets: First, these tenets were identified as central tenets in existing NOS research in science education (McComas, 2020). Second, the existence of naïve or uninformed conceptions is mostly based on these identified tenets of NOS (Bayir et al., 2014;

Buaraphan, 2011; Irez, 2006; Kite et al., 2020; Reiners et al., 2017; Wahbeh & Abd-EI-Khalick, 2013). In the subsequent sections, each tenet conceptualised for this study was discussed briefly.

Scientific Knowledge

In-service and pre-service science teachers frequently hold the belief that scientific findings are final and binding, which leads to the assumption that scientific knowledge is absolute (Karişan & Cebesoy, 2018; Kite et al., 2020; Wangdi et al., 2019). Science is unique in nature that it is subject to revision based on the scientific community's evaluation as new evidence is presented and new insights are gained. That is, scientific findings are durable, but they can be overturned if new evidence and explanations emerge (McComas, 2020).

Experiments, which are primarily used to confirm scientific ideas and discoveries, are frequently misunderstood as the principal route to scientific knowledge. Scientific experiments are valuable tools in science, but they are not the primary means of generating scientific knowledge. Many scientists also use non-experimental methods to derive scientific knowledge, such as observations, analysis, speculation, or library research (McComas, 2020). Experiments can confirm a theory's error or provide evidence for a theory to be tested, but they are incapable of declaring what is correct (Jain et al., 2013; Lombrozo et al., 2008). In contrast, scientific models are exclusively used as learning tools to enhance explanations, trigger discussion, or generate predictions, which leads to frequent misunderstanding that they are copies of the realities (Buaraphan, 2011). Scientists employ scientific models to explore complex systems, explore unknown possibilities, develop conceptual frameworks, generate accurate predictions, and propose causal explanations (Gogolin & Kruger, 2018). The use of scientific models enhances thinking, visualisation, and compherension of a phenomenon (Krajcik & Merritt, 2012).

Scientific Theories and Laws

Generally, there is a widespread misconception among people regarding the hierarchical relationship among hypotheses, scientific theories, and laws (Reiners et al., 2017; Schwartz & Lederman, 2008). Many mistakenly believe that hypothesis, with the accumulation of evidence, become theories which, in turn, evolve into laws. However, it is important to recognise that hypotheses, theories, and laws are different entities of scientific knowledge. In practice, hypotheses could be defined as tentative laws, or tentative theories; laws as generalisations, or patterns in nature; and theories as explanations of those generalisations (Buaraphan, 2011).

Another common misconception that many hold is about the laws-in-mature-theories-fables that potentially causes one to conclude that scientific theories are less secure than laws. For example, in Buaraphan's (2011) study, most pre-service science teachers stated that laws are more accurate than scientific theories because scientific theories are repeatedly tested and verified to become laws. Although there is a link between theories and laws, one cannot simply become the other under any condition (McComas, 2020). Considering hypotheses as an educated guess is another common misconception among students (McComas, 2020). Students mistakenly assume that hypotheses are merely predictions made before any scientific research based on prior information, which is not the case. The expected outcome of scientific investigation is known as a prediction, whereas the proposed explanation or description of a phenomenon is known as a hypothesis (Eastwell, 2014). In the proper context, trial laws could be termed as generalising hypotheses, and trial theories as explanatory hypotheses (Eastwell, 2014; McComas, 2020). This means that, with valid evidence, generalising hypotheses may become laws and explanatory hypotheses might become theories.

Scientific Methods

Studies have indicated that misconceptions related to scientific methods are the most prevalent misconception in science among students and teachers (e.g., Irez, 2006). There is a misunderstanding that the scientific method is a fixed, step-by-step process that has to be followed sequentially without skipping any step to generate the desired results (Bayir et al., 2014; McComas, 2020). Majority of scientists employed in the study by Bayir et al. (2014) had the notion that the scientific method is an absolute and universally prescribed inquiry to discover scientific insights. Despite the existence of shared methods such as induction, deduction, and inference in science, there is no standard fixed method that all scientists follow to generate scientific knowledge (McComas, 2020).

This perceived misconceived notion that the scientific method is a fixed, step-by-step process could have further led to the naïve understanding that science is more procedural than creative. There is no guarantee that two scientists with similar intellectual backgrounds reviewing the same facts would come to identical conclusions. The process of scientific inquiry is largely influenced by the creativity of individual scientists (McComas, 2020). Although scientific inquiry has its limitations, it is often misconceived as a universal inquiry that can address all issues. Thus, science and its methods can potentially address all questions – is another most prevalent misunderstanding about science. It is obvious that while science may be able to offer certain insights that may be instructive, it cannot really address questions that are outside the scope of scientific investigation, such as those that are related to moral, ethical, aesthetic, social, and metaphysical concerns (McComas, 2020).

Scientists' Work

A common misconceptions associated with the nature of scientists' work include that creativity and imagination are not used in generating scientific knowledge, scientists are unbiased in proposing scientific conclusions, and all scientific conclusions are accepted after a thorough review by others. The misconception regarding the use of creativity and imagination in science has mainly originated from the incorrect notion that scientific methods are fixed, step-by-step processes (Irez, 2006). However, creativity and imagination of the individual scientist or a team play a vital role in the discovery of laws and the invention of scientific theories (Bayir et al., 2014; McComas, 2020).

Some scientists may discover a pattern in the data and propose or generalise a theory or a law, but there is no common procedural method in which the pattern is perceived. Scientists, like all other observers, would perceive the occurrence of the phenomenon through the lens of their prior knowledge and experience and have biases in generating scientific knowledge (Buaraphan, 2011; McComas, 2020). While professional scientists should review each other's findings to reach a scientific conclusion that is acceptable, this is not always possible due to their busy schedules and a lack of research funding (McComas, 2020).

Scientific Enterprise

Science and technology are misconceived to be identical (Buaraphan, 2011) and often used interchangeably (Wangdi et al., 2019). There is an interplay between science and technology, but they are never the same. Science is described more as a process of scientific inquiry in understanding the natural world. Technology is the means of modifying the natural world that suits human needs or desires (Rau & Antink-Meyer, 2020).

Social and cultural factors influence scientific works, as a significant portion of scientific research relies s on external funding controlled by the government or the private sectors with their own agenda (McComas, 2020; Schwartz & Lederman, 2008). Moreover, scientific conclusions proposed by scientists only become part of the shared knowledge once they have been verified by the scientific community (McComas, 2020). The notion of science as a solitary pursuit is another misconception. Many scientific issues are complex and challenging for individual scientists to take up due to limitations such as time, intellectual capacity, and financial resources. In such cases, scientists collaborate within a community of similar interests and expertise (McComas, 2020).

Pre-service Science Teachers' Conceptions of the Nature of Science

Since teachers' views of NOS have a direct influence on their classroom practices, pre-service science teachers' informed conceptions of NOS would result in a greater field impact on students' science learning (Jain et al., 2013). Buaraphan's (2011) study that investigated 17 pre-service physics teachers' views of NOS showed that pre-service teachers held informed views on tentative NOS, the role of creativity and imagination in science, scientific enterprise, and the role of scientific experiments. In contrast, pre-service physics teachers had uninformed views related to the relationship between scientific theories and laws, the scientific method, subjectivity, and the distinction between science and technology. The findings were contradictory to the findings of the qualitative study that explored pre-service teachers' conceptions of NOS (Jain et al., 2013).

Akerson et al. (2019) reported a naïve understanding of multiple tenets of NOS. Pre-service teachers held uninformed or naïve understanding of tentativeness, observation, inference, empirical, subjectivity, scientific theories and laws, and socio-cultural influence in science before intervention. However, many of the participants demonstrated an informed view of the role of creativity and imagination in science. This findings aligns with the results of Akerson et al. (2019) study, which showed similar findings to Bell et al. (2016) in examining the effectiveness of NOS instructions. These results were, however, contradictory to other studies (Karisan & Cebesoy, 2018). Karisan and Cebesoy (2018) concluded that pre-service science teachers held informed conceptions of all tenets of NOS, except for scientific theories and laws. Pre-service science teachers held informed conceptions of the role of creativity and imagination in science, and uninformed conceptions of the relationship between scientific theories and laws. Such uninformed conceptions of the hierarchical relationship between scientific theories and laws were also reported (Reiners et al., 2017).

Bhutanese Pre-service Science Teachers' Conceptions of the Nature of Science

The tenets of NOS in Bhutanese science education are identified in the education policy frameworks (Royal Education Council [REC], 2009, 2012), new normal science curriculum framework (REC, 2021), Physics Practical Manuals (REC, 2020), and pre-service science teachers' curriculum (Samtse College of Education [SCE], 2019). Students are expected to understand the nature of scientific knowledge, the process of construction of scientific knowledge, and how scientific knowledge is accepted by the scientific community (REC, 2020, 2021). However, there are no explicit NOS instructions designed for classroom instructions. In this context, Bhutanese science teachers and teacher educators have a significant responsibility to ensure that NOS concepts are effectively conveyed to science students. Wangdi et al. (2019), whose study focused on in-service (N=78) science teachers' conceptions of NOS reported that in-service science teachers held naïve conceptions of NOS. Accordingly, a similar study of NOS with a focus on pre-service science teachers was suggested based on the findings.

Methodology

In this section, we present the systematic way of approaching our study. Details of the research contexts and methods of data collection and interpretation techniques employed in our study are provided

Context of the Study

This study was planned as a cross-sectional study to explore pre-service science teachers' conceptualisation of NOS from the population that was accessible at one specific point in time (Wang & Cheng, 2020). Pre-service teachers in our study refer to Year 12 or general science graduates without teaching qualifications but are currently enrolled in the teacher education programme. A total of 50 pre-service science teachers specialising in the field of teaching Biology, Chemistry, and Physics participated in the study. The demographic details of the participants for the study are given in Table 1.

Table 1
Demographic details of the Participants

Descriptions		Frequency (%)
	Male	27 (54)
Gender	Female	23 (46)
Course	B. Ed (Science)	34 (68)
	PgDE (Science)	16 (32)
	Biology	20 (40)
Majors (specialisation)	Chemistry	17 (34)
	Physics	13 (26)

Data Sources

The Understanding of Nature of Science (UNOS) questionnaire, originally utilised to investigate the conceptions of NOS among in-service science teachers in Bhutan (Wangdi et al., 2019), was adopted in this study due to its contextual relevance. UNOS with an internal consistency of 0.81 comprised 15 two-tier items focused on five tenets of NOS. The first-tier items of UNOS explored pre-service science teachers' knowledge of NOS, and the second tier examined their analytical ability to validate the claim they make in the first tier. The study was administered after the pre-service teachers issued their consent to participate in the study. The confidentiality of the participants was considered to elicit their genuine understanding of NOS. The five tenets of NOS identified in our study are shown in Table 2.

Table 2
Aspects of NOS included in Understanding of Nature of Science

Aspects of NOS	Items number in the UNOS
1. Scientific knowledge	1, 2, 3
2. Scientific theories and laws	4, 5, 6
3. Scientific methods	7, 8, 9
4. Scientist's work	10, 11, 12

5. Scientific enterprise	13, 14, 15

Data was analysed based on assessment criteria shown in Table 3. To reduce assumptions, "I don't know" was also included as an option. Responses that were incorrect on both tiers were given zero. Responses with incorrect options opted in the first tier but correct in the second tier were also marked zero. We assumed that the likelihood of such an occurrence is illogical due to the nature of the two-tier questions – the first tier that simply assesses their knowledge of NOS, and the second tier questions that demands reasoning abilities. Responses of such nature were deemed as complete guessing with a lack of clear reasoning comprehension. Responses were categorised into three levels of conceptions: *uninformed, naïve*, and *informed*. Uninformed conception of NOS was defined when both the tiers were incorrect, or have no/I don't know as responses, or when only the second tier was correct. Responses that were correct in the first tier but reflected incorrect or have "no/I don't know" in the second tier were classified as naïve conception as it implies a deficit of understanding of NOS due to unstable reasoning in the second tier. When both tiers were correct, the responses were considered informed conceptions.

Table 3
Assessment Criteria for the two-tier Items and Levels of Conception

Assessment criteria	**Score**	**Level of conception**
Wrong / No / I don't know in both the tiers	0	Uninformed
Only the reason in the second tier is correct	0	Uninformed
Only the choice in the first tier is correct	1	Naïve
Both the choice and the reason are correct	2	Informed

Findings

The findings of the study are presented under two major themes: Pre-service Science Teachers' Conceptions of NOS and Pre-service Science Teachers' Conceptions of the NOS based on their specialisation, each addressing the research questions of this study.

Pre-service Science Teachers' Conceptions of the Nature of Science

The responses obtained from pre-service teachers were categorised into three levels of conceptions: *informed*, *naïve*, and *uninformed* thereby addressing RQ. 1. UNOS was grouped into five tenets of NOS: scientific knowledge, scientific theories and laws, scientific methods, scientists' work, and scientific enterprises as reflected in Table 4.

Table 4
Level of Conceptions for each Tenet of the Nature of Science

No.	**Tenets**	**Items**	**Level of Understanding f (%)**		
			Informed	**Naive**	**Uninformed**
1	Scientific knowledge	1-3	11.7 (23.4)	0.7 (1.3)	37.7 (75.3)
2	Scientific theories and laws	4-6	2.7 (5.3)	5.0 (10.0)	42.3 (84.7)
3	Scientific methods	7-9	17.7 (35.3)	0.7 (1.3)	31.7 (63.3)
4	Scientists' work	10-12	18.7 (37.3)	10.7 (21.3)	20.7 (41.3)

5	Scientific enterprises	13-15	12.0 (24.0)	7.7 (15.3)	30.3 (60.7)

The findings indicated that the majority of pre-service science teachers have uninformed conceptions of NOS. Based on the five tenets of NOS as conceptualised in this study, the level of conceptions of NOS for pre-service science teachers varied from 25.1%, 9.8%, and 65.1% for informed, naïve, and uninformed respectively. Of the five tenets, pre-service science teachers have the highest level of informed conceptions on the tenet of scientists' work (37.3%). In contrast, they have the highest level of uninformed conceptions of the tenets of scientific theories and laws (84.7%) followed by scientific knowledge (75.3%). Except for scientists' work (41.3%), the other tenets had an uninformed level of conceptions above 60%. In terms of naïve conceptions of NOS, scientists' work (21.3%) has the highest while scientific knowledge and scientific method have the lowest level of naïve conceptions at 1.3% each.

Upon item-by-item analysis, it was found that slightly over half of the pre-service science teachers (58%) held informed conceptions of the tentative nature of scientific knowledge (item 1), scientific methods (item 8), and the role of creativity (item 10) (See Table 5). The role of scientific models (item 3) and definition of hypothesis (item 6) have the lowest level of informed conception with 2% each. Acceptance of scientific conclusions (item 11) has the highest level (50%) of naïve conceptions, whereas the role of scientific experiments (item 2), nature of the scientific method (item 7), and nature of the scientific procedure (item 9) have 0% naïve conception. The highest percentage (96%) of pre-service science teachers have an uninformed conception of the nature of scientific experiments (item 2) and the relationship among hypotheses, scientific theories, and laws (item 4). Similarly, 90% of them have an uninformed conception of the role of scientific models (item 3). For other items (items 5, 6, 7, 9, 12, 13, and 14), data revealed that most pre-service science teachers still possessed uninformed conceptions with the percentage ranging from 66% to 84%.

Table 5
Level of Conceptions for each Item of the NOS

No.	Items	Level of understandings f (%)		
		Informed	**Naïve**	**Uninformed**
1	Scientific knowledge is absolute and therefore cannot be changed.	29 (58)	1 (2)	20 (40)
2	Experiments are the principal route to scientific knowledge	2 (4)	0 (0)	48 (96)
3	Scientific models are copies of reality	4 (8)	1 (2)	45 (90)
4	A hypothesis becomes theories that in turn become laws.	1 (2)	1 (2)	48 (96)
5	Scientific theories are less secure than laws	6 (12)	7 (14)	37 (74)
6	A hypothesis is an educated guess.	1 (2)	7 (14)	42 (84)
7	The scientific method is a fixed, step-by-step process	11 (22)	0 (0)	39 (78)
8	Science and the scientific method can answer all questions	29 (58)	2 (4)	19 (38)
9	Science is procedural more than creative	13 (26)	0 (0)	37 (74)

10	Scientists do not use creativity and imagination in developing scientific knowledge	29 (58)	2 (4)	19 (38)
11	Scientific conclusions are reviewed by others for accuracy	20 (40)	25 (50)	5 (10)
12	Scientists are open-minded without any biases	7 (14)	5 (10)	38 (76)
13	Science and technology are identical	7 (14)	8 (16)	35 (70)
14	Scientific knowledge is an individual enterprise	13 (26)	4 (8)	33 (66)
15	The development of scientific knowledge is influenced by societal (politics, economy, and religion) and cultural factors	16 (32)	11 (22)	23 (46)

Pre-service Science Teachers' Conceptions of the NOS based on their Specialisation

To address RQ. 2, the relationship between pre-service science teachers' conceptions of NOS and their specialisation was examined using a one-way analysis of variances (ANOVA) test. The result showed that there was statistically no significant difference between the subject groups of pre-service science teachers' conceptions of NOS (F [2, 47] =.251, p=.779) at p=.05. This indicates that all pre-service science teachers who specialised in three disciplines of science – biology, chemistry, and physics – have a homogenous level of conceptions of NOS.

Table 6
One-way Analysis of Variance Test

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.952	2	4.476	0.251	0.779
Within Groups	836.968	47	17.808		
Total	845.920	49			

Discussion

This study investigated Bhutanese pre-service science teachers' conceptions of NOS, conceptualised based on the five tenets of NOS namely: scientific knowledge, scientific theories and laws, scientific methods, scientist's work, and scientific enterprises. The study also examined the association between pre-service science teachers' conceptions of NOS and their choice of major elective. The findings revealed that most of the pre-service science teachers have uninformed conceptions of NOS. There was statistically no significant difference between pre-service teachers' subject of specialisation and the conception of NOS.

To address RQ.1- *What are the pre-service science teachers' conceptions of NOS?*, an item-wise analysis was performed. It was identified that pre-service science teachers have informed conceptions on the tentative nature of scientific knowledge, limitations of scientific methods, and the role of creativity and imagination in science. They believed that scientific knowledge is durable and is subjected to revision with the emergence of new ideas or substantiated with valid evidence (Wangdi et al., 2019). In other words, a more reliable and accurate piece of evidence has the potential to invalidate previously gathered evidence supporting the stability of scientific knowledge (Buaraphan, 2011). Pre-service science teachers also possessed an understanding of the limitations of scientific techniques, believing that science and scientific methods cannot solve all ethical, moral, social, theological, and metaphysical concerns (McComas, 2020). In addition, pre-service science teachers had informed conceptions of the role of creativity and imagination in science. They have an understanding that scientists employ their creativity and imagination in generating hypotheses, designing scientific studies, developing scientific theories and models, making judgments about observations, interpreting data, and drawing scientific conclusions. Although contextually different, comparable findings were also available in literature (Bayir et al., 2014; Buaraphan, 2011; Oh, 2017).

The findings of this study revealed that pre-service science teachers have uninformed conceptions of the various tenets of the NOS. Although less than half of the pre-service science teachers had an informed conception of the acceptance of scientific results, most of them have naive conceptions of the subject. This indicated that pre-service science teachers still lack an informed conception of the process of adopting scientific concepts since they were not exposed to such scientific knowledge-creation techniques in their early learning process. They may comprehend that those scientific findings are accepted by common consent, but they may be unaware that scientific conclusions are examined by peers or the scientific community to ensure legitimacy and correctness (McComas, 2020; Wangdi et al., 2019). Similarly, pre-service science teachers had the belief that scientists are professionally committed individuals, who derive scientific conclusions solely using objective experiments and observations (Bayir et al., 2014), which possibly had built an uninformed conception of the subjective nature of scientists' works.

Numerous studies have shown that the most common uninformed conceptions of NOS, even among science teachers, are the idea of a universal scientific approach that consists of a fixed, step-by-step process (Bayir et al., 2014; Irez, 2006; Kite et al., 2020; Oh, 2017) and scientific experiment are only the primary method of generating scientific knowledge (Buaraphan, 2011; Jain et al., 2013). Similar uninformed conceptions of NOS were found in the pre-service science teachers involved in this study. Such uninformed conceptions of NOS may be greatly influenced by the kind of science curriculum instructions introduced to them in their school. In the traditional classroom settings, scientific experiment is usually believed to be the most valid and authentic method to confirm the truth of scientific ideas (Jain et al., 2013), and students carry out scientific experiments by following the prescribed procedures provided in the science textbooks (Buaraphan, 2011). An uninformed conception of scientific methods, in turn, could be the main reason for the belief that science is more procedural than creative (Irez, 2006; McComas, 2020; Wangdi et al., 2019).

Another uninformed conception of NOS in this study that challenged most pre-service science teachers was the hierarchical relationship between hypotheses, scientific theories, and scientific laws (Chaiyabang & Thathong, 2013). Although the context of the studies differs, findings of this study correspond to other studies (Buaraphan, 2011; Demirdogen et al., 2016; Wangdi et al., 2019). Participants held the view that hypotheses can be proven to become theories with sufficient evidence. Similarly, empirically tested theories have the potential to develop into laws (Buaraphan, 2011; Reiners et al., 2017). These uninformed conceptions might have developed due to their exposure to scientific experiments designed to prove certain scientific concepts and theories that were largely practiced in science classrooms (Jain et al., 2013).

Akerson et al. (2009) and Krajcit and Merritt (2012) argued that though scientific models provide powerful tools to explain the occurrence of phenomena, they comprise a set of ideas that only approximate and simplify how each entity of the system works. They added that relying on a single model is often insufficient to adequately study a complex system, as every model has limitations in capturing certain type of information. In contrast, pre-service science teachers of this study held the belief that scientific models express the exact copies of realities that explain the occurrence of natural phenomena with a complete set of ideas, which corresponds to the findings of Buaraphan (2011) and Kite et al. (2020). The uninformed conception of scientific models among these pre-service teachers may stem from the prevalent practice of using the same models repeatedly to illustrate or interpret various phenomena (Wangdi et al., 2019), or primarily employing them as instructional aids for teaching science content (Gogolin & Kruger, 2018) in classroom settings. Similarly, the uninformed conception of the distinction between science and technology by pre-service science teachers of this study could also be due to the casual interchangabe use of the terms (i.e., science and technology) and their notion that artifacts and systems are developed following scientific discoveries. To address RQ.2 - *What is the relationship between pre-service science teachers' conceptions of the NOS and their subject of specialisation?* a one-way analysis of variances (ANOVA) was performed. Although this study indicated a homogeneous level of NOS conceptualisation depending on the field of specialisation (i.e., physics, chemistry, and biology) of pre-service science teachers, we discovered that there are inadequate conceptions of NOS. Such inadequate conceptions of NOS by the pre-service science teachers could possibly be due to limited learning experiences in the teacher preparation modules. This clearly suggested that although the major tenets of NOS are identified in the science curriculum materials and agendas, application in classroom teaching-learning is inadequate.

Study Implications

This study investigated 50 pre-service science teachers' conceptions of NOS and its association with their subject of specialisation in one of the two teacher training colleges in Bhutan. The findings of the study revealed that most pre-service science teachers possessed naïve and uninformed conceptions of NOS based on the conceptualised NOS framework of this study. Specifically, pre-service teachers lacked informed conceptions of the nature of scientific experiments and scientific methods, the relationship between scientific theories and laws, the role of scientific models, science and technology, and the subjectivity in science. There was statistically no significant difference between pre-service science teachers' subject of specialisation and their conceptions of NOS.

Understanding NOS is an important component of scientific literacy that helps improve students' conceptions of science and their capacity to make informed decisions. This is attainable only if science teachers possess informed conceptions of NOS. In contrast, uninformed conceptions would pose negative implications for classroom learning. Equally, if pre-service science teachers graduate with uninformed conceptions about the aspects of NOS, it could lead to a deficient understanding of NOS being passed on to their students. Science teacher educators play a crucial role in fostering scientific literacy by enhancing the informed conceptions of NOS through instructional programmes.

Critical to the success of pre-service teachers' familiarity with NOS is teacher educators and teacher colleges in embracing tenets of NOS into pre-service science teachers' instructional programmes. Inclusions such as this can facilitate preparing pre-service science teachers with an informed understanding of NOS which can impact students' learning. Future researchers can also consider exploring novel ways of delivering NOS content – explicitly and implicitly – in promoting pre-service science teachers' conceptions of NOS. Additionally, given the findings that both in-service teachers (Wangdi et al., 2019) and pre-service science teachers in this study lack informed conceptions of the Nature of science, there is a need for future research to explore how students in classrooms comprehend the principles of NOS.

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