The Myth of Theory and the Theory-Laden Nature of Scientific Knowledge: Views of Senior High School Students

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Abstract

The study aimed to understand Senior High School Students’ perspectives on the myth of theory, law, and the theory-laden nature of scientific knowledge. A qualitative approach was adopted using a case-study design based on the constructivists paradigm. The participants were ten (10) students purposively selected from a Minor Seminary Senior High School in the Upper East Region of Ghana. The school was selected as a case using the extreme-case selection criteria. Instrument used for data collection was the Theory, Law, and Theory-laden Questionnaire (TLT-LQ). The TLT-LQ consisted of four questions on myth of theory and law and the theory-laden or subjective nature of science. The questions were adapted from Items 5 and 8 of the VNOS-C questionnaire. It was found that six students (60%) held naïve views on the differences between a theory and law. They think that a theory is a guess that has not been proven scientifically, whiles a law is a theory that has been proven to be true. Three students (30%) held transitional views on the differences between a theory and law. They correctly stated that theories explain events, but also think that a theory is a hypothesis that has been tested and proven. Thus, they believe in the myth of a hierarchical relationship between a hypothesis and a theory. Nine students (90%) held the naïve view that there is a hierarchical relationship between a theory and a law where a theory becomes law after it has been proven. On the subjective nature of science, five students (50%) held informed views. They understand that scientific knowledge is subjective or theory-laden. They believe that two scientists may see things differently. Also, four students (40%) held a transitional view. The students think that two scientists may get different results and conclusions from the same data set. They believe that two scientists may analyse the same data set differently. They also think that different experimental error can lead to different conclusions, implying indirectly that a scientists’ backgrounds, values, beliefs and training affects the way they interpret data.
Keywords: nature of science, senior high school, theory, law, subjective, theory-laden.


Introduction

A better understanding of the nature of science is thought to enhance comprehension of subject-matter (Lederman & Lederman, 2012). According to Haidar (1999, cited in Aslan & Tasar, 2013), science textbooks commonly depict scientific knowledge as absolute, objective, and separate from human creativity. Psychological and sociological variables have acquired prominence in describing the character of science. Teaching the NOS is emphasised as an educational goal in several educational reforms and curriculum worldwide (Lederman, 2007).

One problem with science education is that teachers often present science content as factual explanations of nature, leading students to view science as a collection of facts. Science, however, is essentially theoretical rather than factual. The essence of science is to create explanatory frameworks that make sense of large amounts of data and have predictive value. Scientists frequently speak as if they are explaining nature, but they are providing hypotheses, models, and other creations derived from the human imagination (Taber, 2017). Understanding the nature of science and scientific progress remains a barrier for students (Hodson, 2003). From a science learning viewpoint, students misunderstand that scientific knowledge is founded on numerous lines of evidence and is prone to change with new lines of evidence or reinterpretation of evidence (Borgerding & Deniz, 2019).

According to Lederman and Lederman (2012), students have a simplified and hierarchical view of the relationship between theories and laws, with ideas becoming laws based on the availability of supporting evidence. Thus, scientific laws are more important than scientific theories. These ideas are incorrect because theories and laws are distinct forms of knowledge that do not evolve into one another (Lederman & Lederman, 2012). Laws are declarations or explanations of relationships between observable phenomena. Theories are inferred explanations for observable occurrences. However, hypotheses are genuine products of research (Lederman & Lederman, 2012). Students frequently believe that theories are scientists' assumptions that they are hoping to prove through experimentation. However, theories constitute the foundation of scientific knowledge. They are more than mere speculations because they must be founded on extensive evidence (Taber, 2017).

Again, students may believe that scientific knowledge is objective. Theoretical commitments, views, prior knowledge, training, experiences, and expectations have an impact on how scientists work. These background elements influence the problems that scientists explore and how they conduct their investigations and interpret their findings. Thus, subjectivity takes an important part in the advancement of science (Lederman & Lederman, 2012). Science is based on creativity and logic in evaluating concepts, however, scientists must first suggest the ideas to be tested. Scientists do not
go straight from data to knowledge without first interpreting it through a conceptual framework. Science advances through the complementary functions of imaginative and logical thought (Taber, 2011; 2017). Thus, this study aimed to answer the following questions: (1) What are senior high school students' views on the nature of theory and law? (2) How do senior high school students view the theory-laden nature of science?

Objectives

1. To determine senior high school students’ views of the character of theory and law.
2. To determine senior high school students’ views of the theory-laden nature of science.

Literature Review

Nature of Science

Science education reform documents emphasise scientific literacy as the primary goal of science education (AAAS, 1993; NGSS, 2013). Scientific literacy is the ability to interpret media representations of science, recognise and appreciate scientific contributions, and use science in daily decision-making (Bell, 2008). The nature of science is now a well-established focus in science education and an important component in defining scientific literacy (Hodson & Wong, 2017). Nature of science combines elements of history, sociology, and philosophy of science, and has been referred to as the epistemology of science, the features of scientific knowledge, and science as a means of knowing (Bell, 2008).

An essential consideration is which components of the nature of science are most appropriate for precisely defining the domain of nature of science for learners to understand (McComas, 2020). There is significant consensus on the nature of science elements that should be addressed in science education (McComas, 2020). Various research on the nature of science continues to use a perspective known as the 'consensus view' (Lederman, 2007). The consensus viewpoint has acquired widespread acceptance in countries around the world (Hodson & Wong, 2017). The consensus view is a collection of principles that present the nature of science-related concepts such as tentativeness, empiricism, subjectivity, theory-ladenness, and the myth of the scientific method, among others (Cullinane & Erduran, 2022). The consensus perspective displays agreement among different philosophical positions about those characteristics of science that learners must know. Researchers argue that the consensus perspective is accessible to students (Yacoubian, 2021; Cullinane & Erduran, 2022). Lederman's (2007) seven tenets of the nature of science are widely accepted (Table 1).

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<th>NOS Tenet</th>
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<tr>
<td>1</td>
<td>Scientific knowledge is based on evidence</td>
<td>Science is built on direct or indirect observations of the natural world. Science is founded not only on empirical facts but also on logical assumptions about evidence. Scientific knowledge is...</td>
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2 Scientific knowledge is durable but also tentative

3 Scientific knowledge involves subjectivity

4 Scientific knowledge involves creativity and imagination

5 Science is a social activity influenced by the sociocultural environment

6 Scientific theories and laws

7 Scientific method

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<td>2</td>
<td>Scientific knowledge is durable but also tentative supported by experimental facts, but it is never proven. Observation and inference are not the same thing. Scientists may draw various conclusions from the same observations.</td>
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<td>3</td>
<td>Scientific knowledge involves subjectivity Scientific knowledge is consistent, yet it is never certain or unambiguously true. Scientific knowledge evolves through evolutionary and revolutionary processes. New data or re-evaluation of old data might cause scientific knowledge to alter.</td>
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<td>4</td>
<td>Scientific knowledge involves creativity and imagination Prior knowledge, experience, values, views, education, and expectations all have an impact on how scientists do research and draw results. As a subject of study grows, the number and severity of conflicts among scientists may decrease.</td>
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<td>5</td>
<td>Science is a social activity influenced by the sociocultural environment Scientists use their creativity and imagination throughout their professional careers. Creativity and imagination are crucial characteristics that distinguish scientists from one another.</td>
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<td>6</td>
<td>Scientific theories and laws Theories are scientific explanations, while laws are scientific descriptions of natural phenomena. They perform distinct functions in science, and there is no hierarchy between them.</td>
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<td>7</td>
<td>Scientific method There is no universal scientific procedure that all scientists used to ensure scientific discovery. Different branches of science utilise various approaches to generate scientific knowledge.</td>
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Source: Adapted from Lederman (2007), cited in Yalaki et al. (2019)

According to Niaz (2009), the scientific education community has reached a consensus on several aspects of the essence of science. Among the characteristics of nature of science are (Niaz, 2009, p. 33) as cited in (Duschl & Grandy, 2013):

- Scientific knowledge relies heavily, but not entirely, on observations, experimental evidence, rational arguments, and skepticism.
- Observations are theory-laden.
- Science is tentative/fallible.
- There is no one-way to do science and hence no universal, recipe-like, step-by-step scientific method can be found.
- Laws and theories serve different roles in science and hence theories do not become laws, even with additional evidence.
- Scientific progress is characterised by competition among rival theories.
- Different scientists can interpret the same experimental data in more than one way.
- Development of scientific theories is based on inconsistent foundations. Scientists require accurate record keeping, peer review, and replicability.
- Scientists are creative and often resort to imagination and speculation.
- Scientific ideas are affected by their social and historical culture.

The National Science Teaching Association (NSTA, 2024) suggests that by the time they graduate from high school, students should comprehend the following principles about the nature of science:
• Scientific investigations use a variety of methods;
• Scientific knowledge is based on empirical evidence;
• Scientific knowledge is open to revision in light of new evidence;
• Science models, laws, mechanisms, and theories explain natural phenomena;
• Science is a way of knowing;
• Scientific knowledge assumes an order and consistency in natural systems;
• Science is a human endeavour; and
• Science addresses questions about the natural and material world.

Theory-Laden Nature of Scientific Knowledge

Scientific knowledge is theory-laden. Scientists’ theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations influence their work. All these background factors form a mind-set that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they interpret their observations (Lederman et al., 2002). Empirical results are laden with values and theoretical commitments, and philosophers have raised and appraised several kinds of epistemic problems that could be associated with theory and/or value-laden empirical results (Boyd & Bogen, 2021).

One of the recurrent issues in the philosophy of science has been the analysis of the possibility that scientific theory influences scientific observation (Brewer & Lambert, 2001). In line with the theory-ladenness and personal differences, scientists are subjective when they begin to study; they have a background and focus (Sormunen & Köksal, 2014).

Philosophers of science education believe that standards for the acceptance of scientific beliefs are subject to social and historical influence (Reisch, 1999). They emphasised that science is a human activity that is subject to human stubbornness (Alters, 1997, p. 41; Reisch, 1999). Lederman (2007) argues scientists do not conduct absolutely objective observations, do not reach objective conclusions and do not evaluate new evidence objectively (cited in Stefanidou & Skordoulis, 2014). According to Lederman et al. (2002), “scientists are human, they learn and think differently, interpret the same data sets differently because of the way they learn and think, and because of their prior knowledge” (p. 516).

The Myth of Theory and Law

Myth of theory is the widespread misconception that as evidence accumulates, scientific theories progress through a developmental phase before being accepted as mature laws (McComas, 1998). The implication is that hypotheses and theories are not as reliable as laws. Theories and laws are different types of knowledge. Laws are natural generalisations, principles, or patterns, whereas theories are explanations for those generalisations (McComas, 1998). Laws and hypotheses are similar but distinct types of scientific knowledge. Hypotheses are distinct but generic forms of scientific knowledge (McComas, 2008). Laws and theories play diverse functions in science, therefore theories do not become laws, even with more evidence (Niaz, 2009).

Laws are descriptive statements about relationships between observable phenomena. Boyle's law, which describes the relationship between a gas's pressure and volume at a constant temperature, is one example. Theories are inferred explanations for
observable facts or patterns in those phenomena. For example, the kinetic molecular theory, which helps to explain Boyle's law. Students frequently adopt a simplified, hierarchical view of the relationship between theories and laws, in which hypotheses become laws based on supporting evidence. Again, students assume that laws have a higher standing than theories. Theories and laws are distinct types of knowledge and are real scientific products, like laws (Lederman et al., 2002).

Methodology

Design
The study adopted a qualitative approach using a case-study design based on the constructivists paradigm. The philosophical position of the constructivist is that constructivism recognises various realities because reality, for an individual, is personally constructed, albeit in a social context (Denicolo, Long & Bradley-Cole, 2016). Constructivists align with a relativist ontological perspective. Relativism claims that because reality is uniquely individual, a person’s ‘truth’ is individually defined (Easterby-Smith et al., 2002). A relativist perspective is appropriate for researchers who seek to explore individual meanings. By falling squarely on individuality, constructivists are not impeded by particular theories, beliefs, mind-sets or preconceived ideas (such as social mechanisms) but remain open-minded and focused on realities experienced, and defined, by individuals themselves (Denicolo et al., 2016).

A case-study is used in qualitative research that is holistic, thick, and is naturalistic. The researcher investigates the properties of a single observation, or a single phenomenon (Tight, 2017). A case study refers to the study of a social phenomenon performed within the boundaries of one social system (the case), or within the boundaries of a few social systems (the cases) in the case’s natural context by monitoring the phenomenon during a certain period (Swanborn, 2010, p. 13), as cited in (Tight, 2017).

Sample and Sampling Procedure
The sample for the study consisted of ten senior high school students purposively selected from a single sex Minor Seminary Senior High School in the Upper East Region of Ghana. For representativeness to reflect on a broader population of cases (Seawright & Gerring, 2008), the school was selected using the extreme-case selection criteria. This is because the school is a category A school. The extreme-case method selects a case because of its extreme value on the independent or dependent variable of interest. An extreme value is an observation that lies far away from the mean of a given distribution (Seawright & Gerring, 2008).

Instruments
The instrument used for the study is the Theory, Law, and Theory-laden Questionnaire (TLT-LQ). The instrument was adapted from the views of nature of science questionnaire form C (VNOS-C) developed by Lederman et al. (2002). The TLT-LQ consisted of four questions on theory and law and the theory-laden or subjective nature of science. The questions were adapted from Items 5 and 8 of the VNOS-C questionnaire (Lederman et al., 2002):

• **Item 5**: Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
Item 8: It is believed that about 65 million years ago, the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two have enjoyed wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

The adapted questions of the TLT-LQ used in this study are:

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

2. Is there a relationship between a theory and a law? Explain.

3. It is believed that about 65 million years ago, the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two have enjoyed wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

4. Is it possible for two scientists to obtain different results and different conclusions from the same set of data? Explain.

Data analysis

Data was analysed through thematic analysis using QDA Miner Lite. Thematic analysis is an epistemologically flexible methodological tool for categorising qualitative data and identifying patterns across data sets (Denicolo, Long & Bradley-Cole, 2016). Thematic analyses move beyond counting explicit words or phrases and focus on identifying and describing both implicit and explicit ideas within the data. Codes were developed to represent the identified themes (Guest, MacQueen & Namey, 2012). The data was categorised into three themes, that is, naïve views, transitional views and informed views of the nature of science. Students’ responses that are consistent with the accepted views of nature of science were categorised as having informed views. Students’ responses that are inconsistent with the accepted views of nature of science were categorised as having naïve views. Students’ responses that contained a combination of informed and naïve views were categorised as transitional views.

Results

Students’ Views on the Character of Theory and Law

This research question sought to determine senior high school students’ views of the differences between theory and law. In response to the differences between a theory and law, it was found that six students (60%) held naïve views. They think that a theory is a guess that has not been proven scientifically, whereas a law is a theory that has been proven to be true. The following excerpts describe their views:

“A scientific theory and a scientific law are different in the sense that a scientific theory is a guess about a certain idea or occurrence which has not been proved experimentally. As research is further done on a particular theory, the theory can be proven to be to be wrong. An example of a theory is Darwin’s theory of evolution. His theory has no experimental bases and is only
a guess. A scientific law has been proven experimentally to be correct without doubt. Thus, a scientific law is definite and cannot be disproved. An example is Mendel’s laws of segregation, independent assortment and recombination”. (#4, Male)

“A scientific theory is a statement that has not been tested. A theory is a set of ideas that explains a system. A scientific law is also a statement that is relevant and is true since it has been tested or experimented on. For example, Dalton’s Atomic theory had a few mistakes since it wasn’t tested but idealised. Scientific theory may give a better explanation to the problem but may either be true or not, since it isn’t tested. Again, Newton took a lot of time in testing and experimenting before bringing the law of gravitation. He gathered enough prove to bring out his law”. (#1, Male)

Three students (30%) held transitional views on the differences between a theory and law. They correctly stated that theories explain events, but also think that a theory is a hypothesis that has been tested and proven. Thus, they believe in the myth of a hierarchical relationship between a hypothesis and a theory. Their views are seen in the following statements:

“Scientific theory is an idea or set of ideas proposed to explain events and which have been tested and proven through scientific experiments and investigations. It is then right to say that a theory is a hypothesis which has been tested and proven by scientific investigation. For example, kinetic theory was primarily proposed to explain the behaviour of gases, but it has been extended to explain a certain event in liquids and solids, whilst scientific law is a statement or collection of statements derived from facts and different experiments and has a wide range of applications. In fact, a law can be expressed as an equation. In a way, a law in a statement form is summarised by an equation. For example, Avogadro’s law”. (#5, Male).

“Yes, theories are more like ideas explaining observed patterns or phenomena in nature. A law is a more concise statement with strong proof of correctness which explains phenomena. Also, theories are likely to be disproven whilst laws are almost impossible to disprove”. (#7, Male).

Only one student (10%) held informed views on the differences between a theory and law. A scientific law describes quantitative relationships between phenomena, such as a universal attraction between objects. Scientific theories are made of concepts that are under common observation or go beyond and propose new explanatory models for the world (Lederman et al., 2002). This is expressed in the following excerpts:

“Yes, there is a difference in that scientific theory provides a comprehensive explanation for phenomena by integrating multiple observations and hypothesis. For example, Dalton’s atomic theory, whilst scientific law describes observed patterns in nature. For example, Ohms law” (#3, Male).

Again, on the relationship between theory and law, nine students (90%) held naïve views. They think that there is a hierarchical relationship between a theory and a law where a theory becomes law after it has been proven. Their views are expressed in the following statements:

“A theory and a law are linked such that, when a scientific idea or proposal (theory) has been scientifically proven to be correct, the theory is then become a law. An example of a theory whose postulates have disproved is Dalton’s atomic theory”.

“The relationship between a theory and a law can be seen or is appreciable in the sense that a law is a proven and tested theory. A law is a statement which was once a theory but because of its ability to withstand time is a prove as a law. So the relationship between theory and law is that a law is a tested theory which is approved and works perfectly well”.
Only one student (10%) held transitional views on the relationship between theory and law. This student thinks that “both laws and theories seek to explain a phenomenon in nature”. However, he failed to understand that laws describe the relationship between natural phenomena, whiles a theory is an explanation of the relationship between natural phenomena.

Students’ Views on the Theory-Laden Nature of Science

On whether two scientists can obtain different results and conclusions from the same set of data, five students (50%) held informed views on the subjective nature of science. They understand that scientific knowledge is subjective or theory-laden. They believe that two scientists may see things differently. Thus, they understand that science is a human endeavour and is subject to the functions of individual human thinking and perceptions (Chalmers, 1999).

The following statements reveal their views:

“It is possible in the sense that both are not having the same mindset to obtain the same results and same conclusions from the same set of data. The experiment that is performed by the two scientists does not have the same observation from the experiment been performed. Also, maybe the two scientists are not working towards a common goal. Different people see things differently. When performing experiment there are some mistakes that are made and because of these mistakes can lead the scientist to different conclusion about the same set of data they are performing” (#6).

“Yes, it is possible since there are many ways they can choose to handle and interpret the data” (#10).

“Yes, because the scientist could have used different methods of analysing the data” (#8).

Four students (40%) held a transitional view. The students think that two scientists may obtain different results and conclusions from the same data set. They believe that the scientists may analyse the data set differently. They also think that different experimental error made by the different scientists can lead to different conclusions. This has an indirect implication on the backgrounds, values, beliefs and training of the scientists, which affects the way they interpret data. The following statements reveal their views:

“It is possible in the sense that both are not having the same mindset to obtain the same results and same conclusions from the same set of data. The two scientists do not have the same observation from the experiment been performed. Also, maybe the two scientists are not working towards a common goal. Different people see things differently. In performing an experiment, there are some mistakes that are made which can lead the scientist to different conclusion about the same set of data” (#8).

“It is possible for two scientists to obtain different results and different conclusions from the same set of data because they both have different ways of analysing the same set of data” (#10).

“This is possible because different individuals (scientist) have different ways of analysing and concluding on set of data obtained” (#2).

Discussion
The purpose of the study was to determine the views of Senior High School Students about the myth of theory and law, and the theory-laden nature of scientific knowledge. The study found that the majority of students (60%) held naïve views on the differences between theory and law. They think that a theory is a guess that has not been proven scientifically, whereas a law is a theory that has been proven to be true. Three students (30%) held transitional views. They stated that theories explain events, but also think that a theory is a hypothesis that has been tested and proven. Thus, they believe in the myth of a hierarchical relationship between a hypothesis and a theory. Also, most of the students (90%) held the naïve views that there is a hierarchical relationship between a theory and a law where a theory becomes law after it has been proven.

The findings of this study agree with other researchers. For example, Griffiths and Barry (1991) reported that scientific theories appeared to be understood by students only in a naïve sense. Also, Miller et al. (2010) reported that students showed notably uninformed views on the distinctions between scientific theories and laws. They reported that the mean scores on the laws and theories component were notably lower (Miller et al., 2010). Agustian (2020) found that students held Naïve understanding of the difference between scientific theories and laws, their distinctive roles in science, and the non-hierarchical relationship between them. Again, Sinthuwa and Kanyaprasith (2015) found that students think that the scientific knowledge became a law when the knowledge was proved several times.

Again, the study found that many of the students (50%) held informed views on the theory-laden or subjective nature of science. They believe that two scientists may see things differently because of their training, background and the way they analyse and interpret data. Also, many of the students (40%) held transitional views and think that two scientists may obtain different results and conclusions from the same data set. However, these students also think that experimental errors caused by the scientists can lead to different conclusions, implying indirectly that a scientist's background and training affects the way they interpret data.

Stadermann and Goedhart (2020) found that the majority of secondary school students thought that scientists developed different interpretations of quantum physics because of their diverse personal backgrounds. The students stated that scientists develop different interpretations because of what they are, their profession, what they are most involved in (Stadermann & Goedhart, 2020). Suzuri-Hernandez (2010) found that many of the students (60%) agreed that personal experience should play a role in what scientists observe, and about half of students agreed with the position that each scientist can propose his or her own explanation. The majority (90%) of the students believe that there can be more than one explanation for the same data (Suzuri-Hernandez, 2010). However, Sinthuwa and Kanyaprasith (2015) discovered that students have misconceptions on the nature of science aspects, such as the subjectivity of scientific knowledge, and believe that scientists interpret experimental results only on the basis of scientific principles.

Conclusion

Researchers agreed that science learning and teaching should be based on epistemology, social structures, and practices. Students’ understandings of the nature of science would influence their understandings of what it takes to learn and practice science (Duschl & Grandy, 2013). It is critical for science teachers to understand that
practicing hands-on activities does not equate to teaching about the nature of science. Learning about the nature of science necessitates open conversation and thought on the nature of scientific knowledge and the scientific endeavor. Students should participate in activities that highlight specific aspects of the nature of science.

Inquiry activities, socio-scientific issues, and historical incidents can all be used to successfully introduce and reinforce the nature of scientific concepts (Bell, 2008). Good science education should provide students with an authentic sense of scientific processes, whether through historically contextualising established science, authentic inquiry activity in the classroom, or the inclusion of current scientific controversies in the curriculum to invite genuinely open-ended discussion. Science teachers must depict the nature of science in their own teaching. Science teachers must raise understanding of the distinction between laws and theories (Schofield et al., 2023), as well as the distinction between hypotheses and theories, which is particularly crucial for senior high school students.

Conflict of Interests

The authors have No conflict of interest.

References


