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INTEGRATING THE NATURE OF SCIENCE IN TEACHING SCIENTIFIC THEORY IN HIGH SCHOOLS IN CAMEROON: CASE STUDY OF THE ATOMIC THEORY

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Abstract:
Questions about the Nature of Science (NOS) have long preoccupied scientists, but recently, researchers in didactics, curriculum designers and science teachers have been concerned about how NOS can improve the teaching and learning of scientific concepts and theories. While some authors have argued that science students be taught about the Nature of Science explicitly, others suggest it should be taught implicitly when teaching scientific concepts. However, not much research has been done on how to implicitly integrate NOS principles in teaching scientific concepts in a competencies-based approach context. We believe that for learners to significantly improve their learning of scientific concepts, they need to understand the Nature of Science. Thus, we propose the tenets of NOS be taken into account in the design of teaching and learning activities in the experimental sciences. This reflective article proposes a didactic strategy to implicitly teach NOS when teaching scientific theories like the atomic theory using problem situations in the context of the competencies–based approach prescribed in Cameroon.

Keywords: nature of science; problem situation; atomic theory; competencies-based approach, Cameroon

1. Introduction

The nature of Science (NOS) refers to the key principles and ideas that underlie the practice and knowledge of science. It encompasses the values, assumptions, and

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methodologies that are characteristics of scientific inquiry and knowledge production. The key tenets of NOS, as agreed by Lederman (2007) and Buaraphan (2010), amongst others include its: tentativeness of scientific knowledge, empirical basis, creativity and imagination, subjectivity and objectivity, theories and laws, social and cultural embeddedness and scientific method.

Atomic theory is a fundamental concept in chemistry, physics, and biology, providing the basis for understanding the structure and behaviour of matter. Despite its importance, teaching atomic theory presents several challenges. Students often have difficulties grasping the abstract and complex nature of atomic theory, such as the nature of atoms and sub-atomic particles, leading to misconceptions even after instruction (Griffiths & Preston, 1992; Harrison & Treagust, 1996). More so, traditional methods, which may rely heavily on rote memorisation and simplify models, often fail to convey the complexity and dynamism of atom theory. From empirical observations, there is a lack of integration of NOS principles in teaching atomic theory, which could help students understand how scientific knowledge evolves and the nature of scientific inquiry. Thus, this study aims to address the challenges of teaching atomic theory by developing innovative teaching strategies incorporating NOS principles and active learning approaches using problem situations.

According to Hansson and Yacoubian (2021), these concerns have led to various conceptualisations and limits of the NOS in recommendations for its teaching. Recently, however, the question of using the Nature of Science as a tool in teaching and learning science has become a central concern for didactic researchers, curriculum developers and science teachers (Ayina *et al*., 2024; Nchia *et al.*, 2024a; Hasni *et al.*, 2020). Some authors (Lederman *et al.*, 1997) believe that learners' acquisition of concepts and the development of scientific skills require an understanding of the scientific thought process. In the same vein, Reif (1995) believes that science teaching should focus much more on the construction of theoretical rather than functional knowledge.

We strongly believe that the use of the fundamental concepts of the NOS as a conceptual tool in the construction of formative problem situations in science is indispensable in our Cameroonian context. Implementing NOS in a competencies-based approach (CBA) to teaching and learning involves integrating scientific literacy, critical thinking, and the understanding of scientific principles into educational practices. By embedding NOS in CBA, students will not only acquire scientific knowledge but also develop essential skills and attitudes that prepare them for the complexities of the modern world.

2. Problem Statement

Several empirical studies have been done on the integration of NOS into science education. Lenderman *et al.* (2002) found that students often hold naïve views of NOS, but specific intervention could significantly improve their understanding. Khishfe & Abd-El-Khalick (2002) found out that explicit and reflective NOS instruction led to significantly improved student understanding of NOS compared to implicit instruction, while Schwartz *et al.,* (2004) realised that students engaged in authentic inquiry activities, with explicit NOS instructions developed more sophisticated understanding of NOS. Most of this research was not designed in a CBA context using problem situations as entry points as adopted by Cameroon.

Recently, the PISA survey conducted by Bret *et al.* (2023) showed a decline in the scientific culture of French learners. This is also true with our experience of teaching and learning science in Cameroon, as confirmed by the number of misconceptions of NOS amongst pre-service teachers noticed by Nchia *et al.* (2024b), whereby more than half of respondents held non-coherent, uninformed views about scientific knowledge, scientific method and scientists' work. The major inconsistency and misconception was about the hierarchical relationship between hypotheses, theories and laws and the cumulative nature of scientific knowledge. These misconceptions were determined by the department the students belong to and not by their age, sex, religion or level of education. This could probably be due to the science textbooks of the explicit process of producing scientific knowledge.

Maurines *et al.* (2013) believe that one of the challenges of science teaching is epistemological in nature, which could unconsciously lead to the transmission of a wrong scientific culture to learners through their didactic practices. Research shows that textbooks also convey a reduced and distorted image of science through the vocabulary used and the didactic approaches employed (Gibbs & Lawson, 1992). Lederman (2007) realised that teachers tend not to offer learners the opportunity to reflect on the process of constructing scientific knowledge.

To improve understanding of scientific activity, a number of studies have suggested placing learners in a researcher's posture (Robardet, 1990; Sawyer, 2006; Allchin *et al*., 2014; etc.), introducing elements of the history of science into the learning process (Abd-el-khalick & Lederman, 2000; Allchin *et al*., 2014; etc.) and, more recently, engaging pupils in school science practices (Hasni *et al*., 2020). It emerges from these studies that very little research highlights the elements of NOS that can be taken into account in the teaching-learning process of scientific concepts, hence the question: how can the fundamental concepts of NOS that can be integrated into the teaching and learning activities of scientific concepts or theories? Though the CBA curriculum prescribes using problem situation, it does not explicitly mention how design problem situations can integrate NOS principles. This paper is a reflection on using a problem situation to integrate NOS in teaching scientific theory with the atomic theory as a case study.

We propose the following steps to effectively Integrate NOS to teach scientific theories, such as the atomic theory, to enhance students' understanding of both the scientific process and the specific knowledge about the atom. This proposal is arrived at after reflecting on the literature on NOS and CBA. We believe the following didactic strategy could be useful.

3. Suggested Didactic Strategy to Solve Problems

3.1 Identify and Define the Key NOS Principles and Competencies That Students Need to Develop

This refers to the embedded NOS characteristics within traditional science subjects like biology, chemistry and physics. This might include, amongst others, competencies stated in the official syllabus, such as:

- **scientific literacy** (understanding scientific facts, concepts, principles, theories and laws in each scientific discipline);
- **critical thinking** (ability to analyse and evaluate scientific information);
- **inquiry skills** (proficiency in designing, conducting, and interpreting scientific investigations); and
- **understanding the scientific method** (knowledge of how science works, including hypothesis formulation, experimentation, observation, and conclusion).

3.2 Applying Didactic Instructional Strategies

Adoption of teaching strategies that promote the understanding and application of NOS, such as:

- **inquiry-based learning** (where the teachers should encourage students to ask questions, conduct experiments, and explore scientific concepts actively);
- **project-based learning** (where teachers should endeavour to utilise projects that require students to apply NOS principles to solve real-life problems); and
- **case studies** (the teachers should guide learners analyse historical and contemporary scientific case studies to understand the nature and process of scientific discoveries).

3.3 Teach the Hierarchy of Scientific Knowledge (Facts ➔ Concepts ➔ Principle ➔ Hypothesis ➔ Theories or Laws)

The teachers should guide learners to appropriate the hierarchy and relationship between scientific terms such as "facts", "concepts", "principles", "theory" and "laws" using experiments and investigations. Understanding the differences between these scientific terms is crucial for grasping how scientific knowledge is structured and how it evolves. For example:

- **Facts** are observable phenomena or pieces of information that are consistently found to be true. They are verifiable through empirical observation and measurements. For example, "***atoms*** *contain negatively charged particles called electrons*" (from Thompson Cathode ray experiments).
- **Concepts** are general ideas or understanding that help to categorise and interpret information. They are mental constructs that help in understanding and organising knowledge. For example, "*the concept of* ***atomic structure*** *posits that atoms consist of a nucleus containing proton and neutrons surrounded by electrons in orbitals*."

- **Principles** are fundamental truths or propositions that serve as the foundation for a system of belief, behaviours, or reasoning. They provide a basis for understanding relationships and processes within a system. For example, *"the principle of **conservation of mass** is that the mass of reactant equals the mass of products in a chemical reaction."*
- **Theories** are well-substantiated explanations of some aspects of the natural world that are based on a body of evidence and multiple tested hypotheses. Theories integrate and explain a wide range of facts and principles. They are predictive and can be used to generate new hypotheses. For example**,** *the "**atomic theory"** describes the nature of matter; it posits that all matter is composed of discrete units called atoms, which are the smallest indivisible particles retaining the properties of an element*.
- **Laws** are statements that describe regular, predictable patterns in nature. They are typically expressed in mathematical form, they are often concise and universal, applying under specific conditions, and they describe how things happen but not why.

According to McComas *et al.* (2002), laws and theories play different roles in science. There is a relationship between laws and theories. A law predicts what will happen, and a theory explains why and how. Laws are derived from tested correlational hypotheses, while theories are developed from tested explanatory hypotheses. Theories do not develop into laws regardless of the relevance of accumulated empirical evidence (a misconception held by many). Laws are generalisations, principles or models and theories are explanations of these generalisations. According to Hasni *et al.* (2020), scientific laws are descriptive statements of the relationships and generalisations observed between the quantities describing a phenomenon. Vorms (2013) indicated that theories are the result of investigation or meticulous observation of certain phenomena and make it possible to predict their behaviour by deduction.

3.4 Proposed Lesson Plan Using Problem Situation

A. Design and Introduce a Veritable Formative Problem Situations on the Atomic Theory

According to Meirieu (1987), Arsac *et al.*, (1988), De Vecchi & Carmona-Magnaldi (2002), a problem situation is a learning context designed by the teacher to engage students in critical thinking and problem-solving by presenting them with a realistic and complex issue that lacks a straight forward solution. It is developed to create cognitive conflict and bring about conceptual change. It requires students to apply their knowledge, skills and understanding to analysis, generate possible solutions, and evaluate the outcomes. It is student-centred as it focuses on student inquiry and active participation. Students take the lead in investigating the problem, formulating hypotheses, and developing solutions. It promotes collaborative learning and can help students effectively learn NOS principles in the context of the atomic theory.

- The first step is to present a **scenario** where students explore the historical development of the atomic model, from Dalton's solid sphere to the quantum mechanical model, focusing on Key experiments and discoveries that shaped our understanding of the atom.
- Students are engaged in a **discussion** about how scientific models evolve and why our understanding of the atom has changed over time.

A good problem situation must have four components: context, task, data and clear instruction of the activities students should carry out using action verbs.

B. Historical Context and Key Experiments

The documents provided for students' perusal should clearly explain the context of the task to solve given the experiment data collected. The teacher should then guide students to understand the significance of the following key experiments related to the evolution of the atomic model and their implications:

- The early ideas of ancient Greek philosophers like Democritus and Leucippus (c.460 – 370 BCE), who first introduced the idea that matter is composed of small, indivisible particles called ***"atomos"*** (meaning indivisible). Although lacking experimental evidence, their philosophical ideas laid the groundwork for later scientific inquiries.
- John Dalton (1766-1844) proposed the **atomic theory** in 1803, which proposed that elements are composed of atoms, and atoms of the same elements are identical in mass and property. The theory provided a scientific basis for understanding chemical reactions and the conservation of masses. His experiments with gases led to the formulation of the Law of Multiple Proportions.
- J.J. Thomson (1856-1940) discovered the electron in 1897 using cathode ray experiments, proving that atoms are divisible and contain smaller charged particles. The **Plum Pudding Model** of 1904 proposed that atoms are composed of electrons scattered within a positively charged "soup". Thompson's work challenged the notion of indivisible atoms and introduced subatomic particles.
- Ernest Rutherford (1871-1937) demonstrated in his gold foil experiment in 1909 that atoms have a dense, positively charged nucleus surrounded by electrons. His **nuclear model,** developed in 1911, introduced the concept of the atomic nucleus and fundamentally changed the understanding of atomic structure.
- Niel Bohr (1885-1962) suggested the **planetary model** in 1913 that electrons orbit the nucleus in fixed energy levels (quantised orbits) and can jump between these levels by absorbing or emitting energy. This model explains atomic emission spectra and introduces the quantum theory concept into the atomic structure.
- Erwin Schrodinger (1887-1961) and Werner Heisenberg (1901-1976) developed the modern **quantum mechanical model** in 1962, describing electrons "motion" as a wave functions (probabilistic electron clouds) rather than particles in fixed orbits paths.

- James Chadwick (1891-1974) discovered the neutron in 1932, a neutral subatomic particle within the nucleus. This discovery completed the basic understanding of atomic structure and explained the mass discrepancy in the atomic nuclei.

The teacher then engages students in a discussion on the implications of each experiment on the atomic model. By recalling the research question or problem behind each of these experiments, the teacher will enable the learners to better understand this evolution. The development of atomic theory, therefore, illustrates a progression from philosophical speculation to a sophisticated scientific model supported by experimental evidence and quantum mechanics. Each key discovery has built upon previous work, leading to the modern understanding of atomic structure as a complex interplay of subatomic particles governed by quantum principles.

A historical and epistemological context is necessary to highlight how scientific ideas evolve over time through observation, experimentation, and evidence collection. This will let learners realise how scientific models or concepts change over time with new evidence and that the current understanding of a concept, theory or model is based on the best available evidence but is still subjected to revision with new discoveries.

This historical approach is in line with the studies by Abd-El-Khalick & Lederman (2000), and Seker & Welsh (2006), who explored how incorporating the history of science into teaching can promote students' understanding and empathy towards scientific culture, including the development of atomic theory.

C. Integration of NOS Principles

a. Empirical Evidence and Data Analysis

Emphasis is made on the role of experiments in shaping atomic theory. Students should analyse data from historical experiments, recreate key experiments (simulations or demonstrations), and discuss how the data support the evolving atomic models. For example, they can recreate Thomson's cathode ray experiment using a simulation. The students are guided to interpret the results and understand how each experiment led to changes in the atomic model.

Scientific explanations must be based on evidence. This evidence is obtained either through experiments in situations ranging from the natural environment to totally artificial situations such as laboratories. To make observations, scientists use their own senses and instruments. In certain circumstances, scientists can deliberately and precisely control experimental conditions in order to obtain evidence.

Observation in science is not limited to perception but also by theory (Hodson & Wong, 2017). The differences between observations and scientific inferences were elaborated by Hasni *et al.* (2020), who mentioned that observations are descriptive statements about phenomena that can be perceived through the senses or observation instruments, whereas inferences are statements about phenomena that are not directly accessible to the senses. As Abd-El-Khalick & Lederman (2000) point out, scientists simply describe and measure things as they perceive them. These observations depend, above all, on their knowledge, beliefs and vision of the world.

Thus, the atomic model enables scientists to use logic and induction to formulate hypotheses or develop theories that provide explanations for phenomena. Scientific knowledge development involves a combination of both observations and inferences (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2000).

b. Tentativeness of Scientific Knowledge

Students examine historical experiments carried out and discuss how the atomic model has changed with new evidence. This demonstrates that scientific knowledge is not static but changes with new discoveries. It is thus possible that another scientific theory could fit an even wider range of observations even better. The evolution of the atomic theory shows its limitations at any given point in time in answering all questions or explaining all natural phenomena. So, the evolution of knowledge is inevitable because new observations can question the dominant theories. Science is. Therefore, it is an evolutionary process in that scientific knowledge is constantly being questioned, modified and improved as new evidence and new discoveries become available. Thus, scientific knowledge is durable yet tentative and subject to change (AAAS, 1990; Popper, 1998; National Science Teachers Association, 2000).

c. Subjectivity and Theory-laden Nature of Observation

Discussion is carried out with students on how different scientists may interpret data differently based on their theoretical backgrounds based on examples provided as case studies.

d. Creativity and Imagination in Science

Students are guided to explore how scientists used creative thinking to develop new models of the atom. Creativity is involved at all stages of scientific investigation and allows us to ask original and interesting questions. It is through creative thinking that scientists build models that enable them to understand or explain the phenomena they are studying. Although scientists use a great deal of imagination and thought to formulate hypotheses and theories, sooner or later, they have to be tested. Science is not an entirely rational or systematic activity (Hasni *et al.*, 2020). It also relies on observation, experimental evidence, rational argument and scepticism (Rubba & Anderson, 1978). Scientific knowledge is thus the product of human creativity and imagination (Aikenhead & Ryan, 1992; Akerson, Abd-El-Khalick, & Lederman, 2000).

e. The Myth of a Single Scientific Method

As McComas *et al.* (2002) point out, there is no single way of doing science; in other words, there is simply no fixed set of steps that scientists always follow, no single path that infallibly leads them to scientific knowledge.

f. The Social and Cultural Roots of Scientific Knowledge
Scientific activity involves many people from all over the world. People from all cultures contribute to science. As a social activity, science inevitably reflects social values and viewpoints. According to Hasni *et al.* (2020), all scientific activity is influenced by the social and cultural context in which it takes place. The direction of scientific research is affected by the prevailing scientific paradigm and/or by political, religious and economic influences.

g. Foster a Reflective and Critical Attitude
Science is a human endeavour, and as such, there is a need to emphasise that science is done by people with diverse backgrounds who bring different insights and biases to their work. The teacher should thus facilitate debates and discussions on scientific topics to encourage students to think critically about evidence and scientific arguments.

h. Address Ethical and Social Considerations of Scientific Theory or Concept
The societal impact of the development of scientific theory and related ethical issues need to be debated, such as its application in technology and society. For example, knowledge about the atomic theory has been used in the development of nuclear energy and atomic weapons. Thus, it agrees with the research of Akerson, Abd-El-Khalick, & Lederman, (2000) that scientific knowledge is socially and culturally embedded.

D. Simulations and Modelling Activity

Interactive simulations are used by students to explore different atomic models and their predictions. Students are guided to discuss how each model explains different observations and what limitations they have. This will enable them to understand why new models were proposed.

E. Reflection and Synthesis (Assessment Methods)

Students are asked to write an essay on the historical development of atomic theories, highlighting the role of Key experiments and NOS principles. The teacher could assign students to evaluate and carry out a critical analysis of the historical and contemporary research papers on the atom concepts, focusing on the methods and evidence used. Evidence-based discussion should be done on how the atomic theory is supported by multiple lines of evidence, including chemical reactions, spectroscopy, and particle physics. Summative assessment should use integrative problem situations or projects that require demonstration of NOS competencies. Students could be asked to write a reflective essay on the impact of NOS on their understanding of the atomic theory.

4. Conclusion

By engaging in this problem situation, students will certainly grasp the fundamental concept of the atomic theory and how they were developed through scientific inquiry. They will appreciate the NOS principles and recognise the importance of empirical evidence, the tentative nature of scientific knowledge, and the role of creativity in science. It will also enhance their ability to analyse data, draw conclusions, and understand the iterative nature of scientific progress. These approaches not only teach the scientific theories effectively but instil a deeper understanding of the processes and principles underlying scientific discovery.

The integration of NOS into science education is essential for fostering a comprehensive understanding of scientific inquiry and knowledge. It empowers students with critical thinking skills, an appreciation of the scientific enterprise, and an ability to engage with scientific issues thoughtfully and with informed consent. Despite challenges, effective strategies for teaching NOS can be implemented to enrich science education and prepare students for a scientifically literate future.

There is a need to complement this reflection with an experimental approach to investigate the effectiveness of integrating NOS in teaching scientific theories using problem situation.

Conflict of Interest Statement
The authors declare no conflicts of interest.

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