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EXPLORING CAMEROONIAN BIOLOGY PRE-SERVICE TEACHERS' CONCEPTUALISATION OF SCIENTIFIC NOTIONS: PATTERNS, MISCONCEPTIONS, AND IMPLICATIONS FOR TEACHER EDUCATION

Lawrence Ntam Nchia[i],
Ayina Bouni,
Judith Ngansop Njomgang
Department of Sciences of Education,
Higher Teacher Training College Yaounde,
University of Yaounde 1,
Cameroon

Abstract:
Scientific literacy is an important aspect of teacher training as it enhances pedagogical competence, fosters critical thinking, addresses misconceptions, aligns with the Nature of Science (NOS), prepares students for a knowledge-based society, and improves science curriculum implementation. This study addresses the conceptualization of some key scientific notions: theories, laws, principles, concepts, and facts by 17 biology preservice teachers. The theoretical framework adopted is Vergnaud's theory of conceptual fields, which allows for a cognitive analysis of conceptualization in learning. A sequential exploratory mixed method was used to identify themes, misconceptions, and correlations among these notions. Results revealed varying degrees of accuracy in understanding: 17.5% demonstrated accurate conceptions, 47.2% exhibited mixed understanding, and 35.3% showed widespread misconceptions. Key misconceptions include viewing theories as mere hypotheses, conflating laws with moral principles, and reducing concepts to observable phenomena. Misunderstandings were more prevalent in abstract notions (theories, principles, and concepts) compared to empirical ones (facts, laws), highlighting the interconnected nature of these notions and key areas for targeted intervention. The study underscores the need for enhanced pedagogical strategies to clarify scientific hierarchies and interconnections in teacher education. Recommendations include targeted epistemological training, explicit NOS instruction, inquiry-based learning, and cognitive change strategies to address these gaps.

Keywords: misconception; pre-service teachers; theories; laws; principles; concepts; facts

[i] Correspondence: email ntam.lawrence@univ-yaounde1.cm

1. Introduction

The terms facts, concepts, principles, hypothesis, laws, and theories all have different meanings in science, although they are often use interchangeably in everyday life. Scientific literacy is foundational for effective preservice science teachers' education, as teachers are responsible for nurturing critical thinking and scientific understanding in future generations (Jurecki, & Wander, 2012; Laius & Rannikmäe, 2014; Jho et al., 2016; Kotuľáková, 2019). However, misconceptions about key scientific notions can hinder this goal, creating didactic obstacles in classroom teaching. According to Carin (1993), facts are products of the empirical activities of science, while concepts, principles, laws, and theories result from analytical activities in understanding, explaining, or predicting phenomena in nature.

2. Literature Review

Scientific literacy in education has been defined as the ability to understand and apply scientific knowledge in real-world contexts (Bybee, 1997). It is essential for teachers to grasp fundamental scientific notions to foster accurate knowledge transfer (Lederman *et al.*, 2002). However, research highlights persistent misconceptions in Preservice teachers' understanding of theories, laws, and principles (Chi, 2005; Ayina *et al.*, 2024; Nchia *et al.*, 2024). McComas (1996) revealed that theories are often perceived as speculative rather than evidence-based.

Giere (1999) argued that theories, laws, and principles are interrelated constructs, yet many students fail to differentiate between their roles and functions. Misconceptions about one notion often cascade, affecting others (Vosniadou, 1994). Few studies have explored preservice teachers' epistemological understanding of these key scientific notions, which are used daily in science lessons, particularly in biology. A study on Cameroonian preservice teachers' conception of NOS by Nchia *et al.*, (2024) revealed that biology teachers exhibited the most misconception about NOS concepts compared to their chemistry and physics counterparts. Addressing these gaps is critical for improving scientific literacy and pedagogical practices (Abell, 2007; Schommer-Aikins, 2004).

Thus, the following research questions were formulated to study preservice biology teachers' conceptions of these key scientific notions, with the aim of identifying patterns, misconceptions and implications for teacher's education:

1) How do biology preservice teachers conceptualize the scientific notions of science, biology, theories, laws, principles, concepts, and facts?
2) What is the prevalence of these conceptions amongst respondents, and to what extent are they correlated?
3) What are the implications of these findings for teacher education programs?

3. Methodology

An exploratory sequential mixed research design was used, as prescribed by Creswell & Plano (2011). Seventeen preservice biology teachers in the second cycle of the Higher Teachers Training College in Yaounde were purposively sampled to represent diverse educational backgrounds from the eleven state universities in Cameroon. Participants, labelled S1 to S17, provided written responses to open-ended prompts exploring their understanding of the five scientific notions.

Thematic analysis was conducted to identify patterns, themes, and misconceptions. The questionnaires were qualitatively analysed by the researchers to identify epistemological and didactic obstacles, which were then quantified using descriptive statistics. Responses were coded inductively, and interconnections between notions were mapped to analyse cascading effects (Duit, Treagust, & Widodo, 2008).

Vergnaud's Theory of Conceptual Fields was used as a robust framework for analysing preservice biology teachers' conceptions of scientific notions (theories, laws, principles, concepts, and facts). It emphasizes the interplay between *concepts*, *situations*, and *schemas*, highlighting how knowledge is constructed and applied across contexts, as indicated by the formula: "$C_{\text{scientific notion}} = f(S, OI, SR)$". Concepts (C) represent mental structures, situations (S) provide contexts in which they are used, schemas (OI) constitute the operational invariants that guide reasoning and problem-solving, and the signifier (SR) represents the symbolic representation of the scientific notion (e.g., linguistics, mathematics, or graphical representation,) as opined by Vergnaud (1982, 1991).

Preservice biology teachers' existing schemas were identified to design teaching activities that enhance assimilation or accommodation of these notions so that their operational and predicative knowledge aligns well with developing scientific literacy.

4. Results and Discussion

4.1 RQ1: Biology Preservice Teachers Conceptualization of Scientific Notions
4.1.1 Qualitative Analysis of Respondent's Conception about Scientific Notion
A. Theories as Coherent, Evidence-based Explanations of Natural Phenomena

There is a general agreement among respondents that theories serve as well-substantiated explanation frameworks for natural phenomena, underpinned by evidence. This view is held by 52.9% of respondents, aligning with the perspective of the National Academy of Sciences (2008), as illustrated by examples such as Darwin's theory of evolution and cell theory.

Only 41.2% of respondents recognise that a theory's explanatory framework is dynamic and evolving. This aligns with the NOS principles, which asserts that scientific knowledge is durable yet tentative and subject to change (AAAS, 1990; Popper, 1998; & National Science Teachers Association, 2000).

Table 1: Qualitative analysis of respondents' conception of a "Theory"

Themes	Codes	Excerpts from Transcript	Inference
Theories as explanatory frameworks, dynamic and evolving	Explanation, Phenomena, Evidence, Evolving	*"A theory is a coherent explanation of phenomena supported by evidence, such as Darwin's Theory of evolution."* (S6) *"A theory is a general and coherent explanation of a set of observed phenomena in biology, such as cell theory."* (S1) *"Theories explain phenomena but may evolve as new evidence arises."* (S2)	**Accurate understanding**
Theories as ideas requiring validation	Theories are equated with hypotheses, Speculation, Validation	*"A theory is a set of ideas, principles, and knowledge limited to speculations requiring experimental verification.* (S10) *"A theory is a kind of demonstration to explain a function or fact. Example: The theory that we inhale oxygen and exhale carbon dioxide."* (S3) *"Theories require validation before acceptance."* (S11)	**Misconception**

Almost half of the respondents (47.06%) held misconceptions about theories, often reducing theme to mere speculations or hypotheses requiring validation (S10 & S11). This aligns with prior research indicating that students frequently misunderstand the rigorous nature of theory formation in science (Lederman et al., 2002). These misconceptions may stem from inadequate emphasis on the iterative process of hypothesis testing and evidence accumulation, which transforms explanatory hypotheses into theories. Additionally, some respondents struggled to distinguish between theories and principles.

For example, some respondents cited the tenets of the cell theory as theories themselves—e.g., "*All living things are composed of one or more cells*" (S5)—or as principles—e.g., "*All cells arise from pre-existing cells by mitosis*" (S7). This suggests difficulty in distinguishing between hierarchical scientific concepts. A theory explains **why** phenomena occur and integrates related principles, laws, and facts, whereas a principle describes **how** phenomena occur or establishes specific biological rules. For instance, the cell theory explains the hierarchical organization of life (Atom → Molecule → Organelle → Cell → Tissue → Organ → System → Organism) and the role of cells in life processes. Similarly, the Theory of Evolution explains biodiversity of life through natural selection, mutation, and genetic drift.

Each of the four tenets of the cell theory represents a principle because principles focus on specific guidelines within a domain. For example, the principle that "*All cells arise from pre-existing cells*" explains the process of growth and reproduction through cellular division in living organisms while refuting the earlier notion of spontaneous generation. Another principle states that *"All cells contain hereditary material (DNA), which is passed from one generation to another"* (S17). This principle underscores genetic continuity and the unity of life, supporting applications such as biotechnology, where the human insulin gene can be inserted into bacteria for insulin production.

B. Laws as Universal Generalizations Derived from Repeated Observations and Consistent Evidence

Table 2: Qualitative analysis of respondents' conception of "Law"

Themes	Codes	Excerpts from Transcript	Inference
Laws as universal generalizations or consistent truth	Universality, Generalization, Consistency, Empirical, Observations,	*"A law in biology is an empirical generalization describing a biological phenomenon observed consistently and universally. Example, Mendel's law"* (S1) *"A law is a generalization describing phenomena consistently, such as Mendel's laws of inheritance."* (S8) *"A law is a concise formulation describing a consistent relationship observed, e.g., the All or Nothing law."* (S13)	**Accurate understanding**
Laws as rules or moral obligations	Rules, Obligations Morals Principles	*"A law is a set of rules established for members of a group by morality or social life. Example: The law of hospitality."* (S11) *"A law is a prescribed rule or obligation people must conform to."* (S17) *"Laws describe absolute truths such as Hardy Weinberg principle."* (S4)	**Misconception**

As shown on Table 2, respondents with accurate conceptions identified laws as empirical generalizations based on consistent observations. This is consistent with the view of Hestenes (1987), who defined a law as a descriptive generalization of how the natural world behaves under stated conditions. Laws summarize consistent observations and describe relationships in nature in either mathematical or qualitative terms. For instance, Mendel's first law of segregation explains how alleles separate during gamete formation, resulting in predictable inheritance patterns. Mendel second law of independent assortment states that alleles of different genes assort independently during meiosis, provided they are on different chromosomes.

However, some respondents misinterpreted scientific laws as moral obligations or social rules, such as respondent S11's statement: *"A law is an obligation to which one must conform, such as the law of hospitality."* This confusion between scientific and societal meanings of "law" highlights the need for precise language in science education.

Another misconception involved overgeneralization, where some respondents viewed laws as absolute and unchallengeable truths, such as respondent S4's statement that *"Laws describe absolute truths such as the Hardy-Weinberg principle."* This reflects a common conflation of the **Hardy-Weinberg principle** and the **Hardy-Weinberg law**. While the **Hardy-Weinberg principle** is a conceptual framework describing conditions under which allele and genotype frequencies remain constant, the **Hardy-Weinberg law** is its mathematical formulation ($p^2 + 2pq + q^2 = 1$). The principle outlines the conceptual basis for genetic stability, whereas the law provides a predictive mathematical model.

C. Principles as Foundational Rules or Truths Guiding Understanding or Actions in Biology

Table 3: Qualitative analysis of respondents' conception of "Principle"

Themes	Codes	Excerpts from Transcript	Inference
Principles as foundational truths	Fundamental, Rules, Guidelines	*"Principles guide the understanding of biological processes, such as osmosis."* (S2) *"A principle is a general rule that explains complex biological processes, for example, the Principle of Homeostasis."* (S16) *"A principle in biology is a general rule or fundamental truth guiding the understanding of biological processes. Example: All living cells are composed of one or more cells."* (S1) *"Principles are fundamental truths, such as the principle of conservation of energy."* (S6)	**Accurate understanding**
Principles methodological, moral guidelines, law or fact	Facts, Goals, Process, Law	*"A principle is a statement or fact that indicates or helps achieve goal."* (S3) *Principles are beliefs that guide behaviour, like not using drugs or smoking."* (S11) *"The origin or cause of something."* (S1) *"A principle is a law rendered plausible through observations and later generalized."* (S17) *"A principle is the same as a scientific law. For example, Mendel laws."* (S10)	**Misconception**

The American Association for the Advancement of Science (AAAS) (1990) defines a principle is a fundamental truth guiding scientific reasoning without necessarily describing exact quantitative relationships. Principles are broad, qualitative, and conceptual but not necessarily universally applicable. For example, the principle of osmosis explains how water moves across cell membranes to maintain balance, while the principle of homeostasis governs how organisms regulate internal conditions like temperature, pH, and glucose levels. Table 3 shows that most respondents (S1, S2, S6, S16, etc.) agreed that principles are foundational in biological understanding.

This concept had the highest proportion of misconceptions (52.94%), with many respondents conflating principles with laws (S17). For instance, Mendel's principle in Genetics is often confused with Mendel's law due to the way it has been taught and learnt (didactic obstacle). Respondent (S10) stated: *"A principle is the same as a scientific law, for example, Mendel laws"*. However, a principle is usually broader and serves as the conceptual basis for laws and theory, whereas a law is narrower and specific, focussing on observable and repeatable phenomena.

Mendel principle, for example, is a broad generalization about inheritance patterns derived from Mendel's experiments and forms the foundation of modern genetics. These include the *Principle of Dominance,* which states some alleles are dominant, and mask the expression of recessive alleles, and the *Principle of Unit Factors*, which states that traits are controlled by discrete units (genes) that exist in pairs. In contrast, Mendel's laws are specific, formalized statements about genetic inheritance derived from repeated experimental observations such as:

- The Law of Segregation - "*During gamete formation, the two alleles for each trait separate, ensuring each gamete receives only one allele*"; and
- The Law of Independent Assortment - "*Alleles for different genes segregate independently of one another during gamete formation (applicable when genes are on different chromosomes)*".

These distinctions highlight common challenges with abstraction and hierarchy in scientific knowledge.

Misunderstandings often stem from oversimplification, as some respondents viewed principles as only methodological (S3) or moral guidelines (S11), ignoring scientific contexts. These misconceptions indicate key areas for targeted intervention. The findings suggest that students may struggle with principles due to their abstract nature and overlap with laws, highlighting the need for clearer distinctions in teaching.

D. Concepts as Theoretical Constructs or Frameworks to Explain Specific Phenomena

Table 4 below shows accurate responses (S6, S7, S8, and S12), in which concepts are framed as abstract representations or theoretical ideas used for understanding phenomena such as homeostasis. This aligns with the views of Duschl (1990), who defined a concept as an abstract idea that explains phenomena, such as natural selection.

Concepts organize facts into coherent frameworks, providing the foundation for developing principles and theories. For example, the concept of heredity informed Mendel's experiments and the subsequent formulation of his laws.

Table 4: Qualitative analysis of respondents' conception of "Concept"

Themes	Codes	Excerpts from Transcript	Inference
Concepts as abstract ideas; mental frameworks; or tools for classification	Abstraction, Ideas, Models, Representation, Understanding	*"A concept in biology is an abstract idea or theoretical model used to explain a specific phenomenon. Example: Ecological balance in ecosystems."* (S6) *"A concept is an idea or abstract category allowing researchers to classify and understand the social world."* (S12) *"A concept helps organize and classify phenomena, like the concept of mitosis."* (S8) *"Concepts are mental representations of phenomena, like homeostasis."* (S7)	**Accurate understanding**
Concepts as an observable phenomenon	Observation Facts	*"Concepts are specific observable phenomena, like mitosis."* (S8) *"A concept is a representation of an observable fact."* (S7)	**Misconception**

We noticed variability in respondents' definitions regarding practical versus abstract applications of the concept. Some respondents oversimplified abstract models, equating concepts with simple observable facts (S7) - *"A concept is a representation of an observable fact,"* which reflects a misunderstanding of the abstract nature of scientific concepts. Emphasizing the role of concepts as scaffolds for building complex knowledge could improve comprehension.

E. Facts as Objective, Observable, and Verifiable Truths

Table 5: Qualitative analysis of respondents' conception of "Facts"

Themes	Codes	Excerpts from Transcript	Inference
Facts as objective truths Facts as empirical observations	Observation, Evidence, Verifiable, Reality	*"A fact in biology is an objective and verifiable observation about a specific aspect of life. Example: DNA is the carrier of genetic information."* (S1)	**Accurate understanding**
Facts as personal truth	Personal Truth	*"Facts are events like the birth of a child." - S14"* *"Facts are observations that may require theoretical validation."* (S10)	**Misconception**

Respondent S1 in Table 5 correctly perceives facts as direct, objective, and verifiable observations of phenomena in congruent with Giere *et al.* (2006), who defined a fact in science as an objective observation universally accepted as true. Facts are the building blocks of scientific inquiry, forming the empirical basis for higher constructs. For example, the observation that pea plants exhibit specific traits laid the groundwork for Mendel's laws.

Misconceptions in this category were minimal, however, some respondents equated facts with subjective experiences. For instance, S10's statement - "*Facts are observations that may require theoretical validation*" – suggests conflation of empirical or interpretative truths. Reinforcing the empirical basis of facts in science education could help address this confusion.

4.1.2. Conclusion on RQ1

Findings revealed that most exhibit a foundational grasp of scientific notions but struggle with differentiating abstract from empirical notions (e.g., concepts versus facts, theories versus hypotheses). Misconceptions were more prevalent in abstract notions such as theories, principles, and concepts compared to empirical ones like facts and laws. The cascading effects of misconceptions suggest that misunderstandings of one scientific notion (e.g., theories) often propagate to related notions (e.g., concepts and facts), highlighting the interconnected nature of these ideas.

According to Vergnaud's theory of conceptual field, these misconceptions may stem from incomplete or conflicting schemas that preservice teachers activate when engaging with scientific notions. For example, conflating laws with societal rules, viewing theories as mere hypotheses, conflating laws with moral principles, and reducing concepts to observable phenomena.

Most respondents correctly distinguish between abstract and empirical notions. Variations arise in definitions of theories, laws, and principles, with overlaps and reveal occasional misuse of terms. These insights highlight the importance of targeted interventions in teacher education to strengthen epistemological clarity and interconnections among scientific notions.

While some students demonstrated a robust grasp of the hierarchical and interconnected nature of scientific constructs, others exhibited widespread misconceptions, with cascading effects observed across notions. These findings highlight the urgent need for targeted interventions in teacher education programs.

4.2 RQ2 – Prevalence of Preservice Biology Teachers' Conception

4.2.1 Accurate Conceptions of Scientific Notions

Table 6: Descriptive statistics for respondents' conception of the five scientific constructs

Scientific Notion	(%) Accurate Understanding	(%) Misconceptions	Common Misconceptions
Theories	52.94% (9 /17)	47.06% (8/17)	Equating theories with hypotheses or unverified speculation: *"A theory is an idea or hypothesis that explains phenomena."* (S14)
Laws	58.82% (10/17)	41.18% (7/17)	Interpreting laws as moral/ethical principles: *"A law is an obligation to which one must conform, such as the law of hospitality."* (S11)
Principles	47.06% (8/17)	52.94% (9/19)	Misunderstanding principles as behavioural guidelines: *"Principles are beliefs that guide behaviour, like not using drugs or smoking."* (S11) or Confusion with laws: *"A principle is the same as a scientific law."* (S10)
Concepts	64.71% (11/17)	35.29% (6/17)	Confusing concepts with observable facts: *"Concepts are specific observable phenomena, like mitosis."* (S8)
Facts	70.59% (12/17)	29.41% (5/17)	Viewing facts as subjective or context-dependent: *"Facts are events like the birth of a child."* (S14) Confusion between facts and theories: *"Facts are observations that may require theoretical validation."* (S10)

The majority of respondents correctly understood the constructs of "Fact" (70.59%) and "Concept" (64.71%), likely due to their foundational nature in biology education. "Law" (58.82%) and "Theory" (52.94%), had moderately accurate responses suggesting partial comprehension. Accurate understanding of "Principle" was lowest (47.06%), indicating potential confusion about its distinction from laws and theories.

4.2.2 Misconceptions of Scientific Notions

From Table 6 above, we noticed that misconceptions were highest for "Principle" (52.94%), possibly due to vague interpretations and overlaps with laws and concepts. Often, the term "*principle*" is used in science to mean the same thing as "*law*" due to didactic obstacles, as the case with Mendel's principle versus Mendel's law or Hardy-Weinberg Principle with Hardy-Weinberg Law.

Misconceptions about "Theory" (47.06%) suggest a lack of clarity about the role of evidence and coherence in scientific theories. These misconceptions could result from epistemological obstacles since, in everyday life, when people say, "*I have a theory*," they often mean, "*I have a hypothesis.*" Technically, a hypothesis is any testable guess. Misconceptions about "Law" were found in 41.18% of respondents.

Misconceptions are more prevalent in abstract notions (*theories, principles, and concepts*) compared to empirical ones (*facts, laws*). Concepts, principles, and pheories are abstract because they involve mental models, generalized truths, or broad frameworks for understanding complex phenomena. They may not directly correspond to observable or measurable entities but are inferred from empirical evidence. Facts and Laws, however, are grounded in observable, measurable phenomena. Facts are specific observations, while laws describe repeatable patterns based on evidence. Both are tangible and directly verifiable.

4.2.3 Correlations between Scientific Notions

Students-teachers with widespread misconceptions, such as respondents S10, S11, and S14, exhibit systemic misunderstandings, often conflating abstract and empirical notions. There is a cascading effect of misconceptions, whereby misunderstandings of one scientific notion (e.g., theories) often propagate to related notions (e.g., concepts and facts), highlighting the interconnected nature of these ideas. This following examples illustrate this phenomenon:

4.2.3.1 Theory Misconception Correlates with Concept and Fact Misconceptions

Respondent S14 views theories as speculative hypotheses rather than evidence-based frameworks: "*a theory is a speculation about a phenomenon that needs to be verified*." This influences their understanding of concepts, leading to oversimplification such as: "*concepts as specific observable phenomena*". This also causes confusion about facts (e.g., "*as an event or occurrence*") without any scientific grounding. A lack of clarity in theories creates difficulty in distinguishing between abstract and empirical constructs, blurring concepts and facts.

4.2.3.2 Law Misconception Correlates with Principle and Fact Misconceptions

Misunderstandings in the distinctions between laws and principles correlate with misconceptions about theories and facts, indicating a systemic issue in distinguishing levels of abstraction.

Respondent S11 interprets laws as moral rules (….*"A law is a set of rules established for members of a group by morality or social life. Example: The law of hospitality.")*, leading to principles being described as beliefs rather than scientific fundamentals (….."*Principles are beliefs that guide behaviour, like not using drugs or smoking.")*. This cascades to facts being loosely defined as subjective experiences (….."*Memory as a fact, like the birth of a child*"). Misunderstanding the empirical basis of laws undermines the grasp of hierarchical relationships between principles, laws, and facts.

4.2.3.3 Concept Misconception Correlates with Theory and Fact Misconceptions

Respondents who view theories as speculative often confuse concepts with facts, suggesting a link between their understanding of abstraction and empirical evidence.

Respondent S10 sees concepts as: …*"a representation of observable facts"*, which leads to theories being seen as speculative ideas and facts as context-dependent observations; …*"theory is a set of ideas limited to speculation requiring experimental verification"*. Misinterpreting concepts affects the ability to form abstract theoretical frameworks and undermines the perception of facts as objective truths.

Quantitative analysis revealed that 17.65% (3 out of 17) of respondents had consistently accurate conceptions. These three preservice teachers (S1. S6. S13) demonstrate clear, scientifically accurate understanding across all or most of the five notions. From Vergnaud's Lens, their declarative knowledge was accurate from their definition of the five scientific notions.

Also, their understanding of these constructs remains consistent across different situations (e.g., they correctly differentiate between a principle and a law in both genetics and cell biology) and they rightly classify Mendel's findings as a law, Darwin's evolution as a theory, or osmosis as a principle.

- S1: Displays accurate descriptions of theories, laws, principles, concepts, and facts, with strong examples such as: *"DNA is the genetic material"* – for a fact; *"All living things are composed of one or more cells"* – as a principle, and "*the theory of evolution by Darwin."*- for a theory
- S6: Provides precise and coherent explanations, distinguishing theories from hypotheses and recognizing concepts as abstract ideas (e.g., *"the principle of conservation of energy"* and "*the concept of ecological balance*").
- S13: Accurately defines all notions, such as theories being supported by solid evidence and laws, as concise, consistent generalizations (e.g., "*Mendel's law of inheritance*").

Students with an accurate understanding of theories often displayed coherent knowledge across notions, highlighting the interdependence of scientific concepts. Student-teachers with accurate understanding, respondents S1, S6, and S13 serve as examples of well-rounded scientific literacy.

Globally, 35% of respondents, that is, 6 out of the 17, had predominant misconceptions across most notions. We noticed inconsistencies in the schemas preservice teachers use when reasoning about these scientific constructs and how these schemas influence their understanding. Their operational knowledge was wrongly used in different biological scenarios. They displayed misconceptions in all or most of the notions, indicating a broader misunderstanding of scientific frameworks. For example, respondent S11 frequently conflates scientific notions with moral, ethical, or societal principles (e.g., "*laws as rules for group conduct*" and "*principles guiding personal life decisions"*); respondent S10 misunderstands key distinctions, such as equating theories with speculation and principles with rules for achieving objectives; and respondent S14 demonstrates repeated conflation of concepts with observable phenomena and facts with subjective or context-dependent events.

47.65% of respondents had mixed understanding, that is, respondents with accurate conceptions for 4-5 scientific notions but misconceptions in others.

4.3 RQ3: Implications of these Findings for Teacher Education Programs

One effective didactic strategies for teaching scientific concepts is considering students' misconceptions to develop appropriate objective-obstacle aimed at overcoming the identified epistemological or didactic obstacles. This gives a positive status to error in a constructivist approach where learning is brought about by conceptual change. Cameroon's competency-based approach with entry through real-life problem situations requires teachers to construct problem situation. Vergnaud's Theory of Conceptual Field (1991) and Brousseau's Theory of Didactic Situation should be applied in constructing true problem situations to overcome identified misconceptions that hinder scientific literacy.

Improving scientific literacy among preservice biology teachers requires targeted interventions that address both content knowledge (facts, concepts, principles, theories, laws) and process skills (scientific reasoning, critical thinking). The study suggests several approaches:

4.3.1 Conceptual Change Strategies

Misconceptions can be corrected by creating cognitive dissonance and fostering new, scientifically accurate understandings. This involves confronting misconceptions with real-world examples or counterexamples. Learners are then guided to resolve conflicts through evidence-based discussions and activities, thereby facilitating conceptual reconstruction. For example, analysing case studies that show how evidence supports theories and leads to laws can be effective. Studies by Lederman *et al.* (2002) and Campbell & Reece (2005) highlights the importance of explicitly addressing misconceptions to improve scientific literacy.

4.3.2 Inquiry-based Learning

Teachers should design structured inquiry tasks where students generate hypotheses, conduct experiments, and analyse results. This hands-on approach can enhance understanding scientific constructs. Simply experiments, like exploring osmosis through the effect of salt concentration on potato mass, can help learners connect scientific concepts to evidence. Teachers should use prompts to guide students through the scientific process (e.g., "What evidence supports your conclusion?"). Encouraging preservice teachers to explain how their findings relate to scientific constructs like theories, principles, and laws would enhance science literacy.

4.3.3 Explicit Instruction on Nature of Science (NOS)

Teaching the distinctions between theories, laws, principles, concepts, and facts explicitly, accompanied by concept mapping and historical examples, can improve comprehension.

The use of historical examples to illustrate the development of scientific ideas over time is crucial. For example, discussing the progression from Darwin's observations to the modern synthesis of evolutionary theory. Integrating discussions on NOS into biology topics like the development of cell theory will illustrate the evidence-based nature of scientific theories. Studies by Akerson *et al.* (2010), Ayina *et al.* (2024), and Nchia *et al.* (2024) have explicitly shown that NOS instruction improves understanding of scientific constructs.

4.3.4 **Epistemological Training**

Incorporating discussions on the nature and evolution of scientific knowledge can help avoid rigid interpretations of scientific notions and mitigate misunderstandings.

To enhance scientific literacy among biology preservice teachers, a combination of explicit NOS instruction, inquiry-based learning, cognitive change strategies, and reflective practices is essential. Tailored professional development and formative assessments ensure these interventions are both effective and sustainable.

5. Conclusion

The study underscores the need for enhanced pedagogical strategies to clarify scientific hierarchies and interconnections in teacher education. By implementing conceptual change strategies, inquiry-based learning, and explicit NOS instruction, teacher training programs can improve pre-service biology teachers' understanding of key scientific constructs, ultimately enhancing scientific literacy in classrooms.

Conflict of Interest Statement

The authors declare no conflicts of interest.

About the Author(s)

Lawrence Ntam Nchia (PhD) is a Senior Lecturer, researcher, and specialist in Biology didactics at the Higher Teachers Training College in the University of Yaounde I. He is interest in using nature of Science (NOS) as a tool to enhance the teaching and learning of Biological concepts in. His key interest is developing didactic strategies to overcome students' misconception and bring about conceptual change in biology education.

Ayina Bouni (PhD) is an Associate Professor, researcher, and specialist in chemistry didactics at the Higher Teachers Training College in the University of Yaounde I. He is interest in using NOS to enhance the teaching and learning of scientific concepts in chemistry and physics education. He has published a lot on the foundation of the Natyre of Science and its implication to teaching and learning physical science.

Judith Ngansop Njomgang (PhD) is an Associate Professor, researcher, and specialist in didactics of Mathematics at the Higher Teachers Training College in the University of Yaounde I. She is interested in developing didactic strategies to overcome learners' epistemological and didactic obstacle appropriate mathematics concept of logic and mathematic language used in the teaching and learning of mathematics concepts in secondary schools in Cameroon. In addition to research and teaching, she is the secretary general of ADiMA – "Association de Didacticiens des Mathématiques Africains".

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