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Understanding the nature of science in biology education: A meta-analysis of students' and teachers' views in senior high schools

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ABSTRACT

This meta-analysis investigates the perspectives of senior high school biology students and teachers on the nature of science (NOS), aiming to identify common understandings, misconceptions, and instructional challenges. The study synthesizes findings from peer-reviewed articles, dissertations, and credible institutional reports published between 2000 and 2023. Using a systematic search across databases such as Google Scholar, ERIC, and JSTOR, and guided by clear inclusion criteria, the analysis incorporates both qualitative and quantitative data. Thematic synthesis and meta-analytic techniques were employed to explore trends, misconceptions, and the impact of teacher professional development (PD) on NOS instruction. Results indicate that while biology teachers tend to possess a more advanced understanding of NOS than students, significant gaps and misconceptions persist among both groups particularly regarding the tentative nature of scientific knowledge and the distinction between scientific laws and theories. Furthermore, the study finds that although PD can enhance teachers' conceptual and pedagogical grasp of NOS, curriculum constraints often limit effective classroom implementation. The findings underscore the need for curriculum reform and targeted teacher training to enhance science literacy and foster accurate conceptions of NOS in secondary education.

Keywords: nature of science, biology education, misconceptions, professional development, science literacy

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INTRODUCTION

The nature of science (NOS) remains a cornerstone of scientific literacy and has been widely recognized as essential for preparing scientifically informed citizens (Lederman et al., 2019). Recent research continues to underscore the importance of developing both students' and teachers' conceptions of NOS to promote critical thinking, informed decision-making, and deeper engagement with scientific content.

One persistent issue in science education is the prevalence of misconceptions among students. Numerous studies, including those by Khishfe and Abd-El-Khalick (2002), have documented that many students view scientific knowledge as a fixed body of facts rather than a dynamic, evidence-based, and revisable process. More recent investigations, such as Lederman et al. (2019), confirm that even in inquiry-based learning environments, students struggle with the idea that scientific knowledge is tentative and constructed through social and empirical processes.

Teachers, as mediators of science knowledge, play a pivotal role in shaping students' understanding of NOS. However, despite their more advanced conceptual frameworks, biology teachers themselves may harbor incomplete or inconsistent views of NOS. For example, the misconception that scientific theories evolve into laws still persists among in-service teachers, as shown by studies conducted in both developed and developing countries (Erdas Kartal et al., 2018). These conceptual gaps have significant implications for how NOS is taught in the classroom.

An emerging body of literature emphasizes the impact of professional development (PD) on teachers' NOS understanding. Sustained, reflective, and inquiry-based PD programs are associated with significant gains in both content knowledge and pedagogical content knowledge related to NOS (Capps et al., 2012; Murphy, 2017). Recent meta-analyses indicate that PD interventions which incorporate explicit and reflective approaches are more effective than implicit or traditional methods (Dogan, 2021).

Curriculum structure is another critical factor influencing NOS instruction. Traditional curricula often marginalize NOS by embedding it in isolated units without sufficient depth or continuity (Khishfe & Lederman, 2007). Calls for curriculum reform advocate for the integration of NOS across all science disciplines with clear learning objectives, appropriate assessment tools, and historical case studies that illustrate the evolving nature of scientific knowledge (Kampourakis, 2020).

In regions such as sub-Saharan Africa, context-specific challenges further complicated NOS instruction. These include lack of teacher support, insufficient resources, and an overemphasis on rote memorization and exam preparation (Ogunniyi, 2023; Adu-Gyamfi, 2014). Nevertheless, studies from Ghana and Nigeria suggest that incorporating culturally relevant content and increasing access to hands-on activities can improve both teacher and student engagement with NOS (Ogunniyi, 2023).

Moreover, the role of teachers in developing students' understanding of NOS cannot be overstated. Teachers' own conceptions of NOS significantly influence their instructional practices and how they present NOS to their students (Akerson & Hanuscin, 2007). If teachers lack a sound understanding of NOS, they may perpetuate students' misconceptions, further hindering the development of scientific literacy (Lederman, 1992). Research has shown that many science teachers themselves harbor incomplete or incorrect views of NOS, which impacts their ability to effectively teach it of which Biology teachers are not an exception (Abd-El-Khalick & Lederman, 2000).

One major challenge teachers' face in teaching NOS is curriculum constraints. Traditional science curricula often prioritize content knowledge over the epistemological aspects of science, leaving little room for explicit instruction on NOS. In addition, PD programs focused on NOS are often inadequate, leaving teachers illequipped to address NOS in their classrooms (Akerson & Hanuscin, 2007). As a result, teachers may struggle to find the time and resources necessary to teach NOS effectively.

Integrated science places emphasis on the approach to teaching process so as to enable the student acquire basic skills of observing, manipulating and classifying. If it is possible integrated science lessons/class are not expected to be classroom chalk-board and talk clarification, enter education approach problem solving concept mapping, Human material and natural resources, using stimulation, games because it is a subject that is designed to involve student in the acquisition of a series of process skills. As Ogunniyi (2023) noted, the result of investigations and research findings embarked upon by many educational researchers among other things showed beyond reasonable doubt that drawbacks or failure of many students is caused by

(a) insufficient teaching and learning materials,

(b) poor time management,

(c) insufficient content knowledge,

(d) students' challenges understanding the lessons taught,

(e) student indiscipline,

(f) students' disinterest in science courses,

(g) science teachers' incapacity to finish the syllabus, and

(h) insufficient hands-on activities in integrated science lessons.

Research on NOS suggests that teacher PD can play a key role in improving teachers' understanding and teaching of NOS. PD programs that are focused on NOS can enhance teachers' content knowledge, pedagogical skills, and instructional practices related to NOS (Akerson & Donnelly, 2010). These programs can help teachers develop strategies for integrating NOS into their science instruction, even within the constraints of a content-heavy curriculum (Capps et al., 2012). Furthermore, PD has the potential to reduce the misconceptions held by teachers, thereby positively influencing student learning outcomes.

This meta-analysis aims to synthesize existing research to examine the views of both senior high school biology students and teachers regarding NOS. Additionally, it explores how PD programs can impact teachers' understanding and instruction of NOS, as well as the common misconceptions held by both students and teachers.

This meta-analysis is directed by the study questions "What are the general views of senior high school biology students regarding the NOS?", "How do biology teachers conceptualize NOS, and how do these conceptions influence their teaching practices?", "What common misconceptions about NOS are held by students and teachers?", and "How do curriculum, PD, and classroom practices impact both students' and teachers' understanding of NOS?" In view of this, effort was made to review related literature to address issues of concern.

METHOD

Search Strategy

To conduct this meta-analysis, a comprehensive search was carried out using well-established electronic databases, including **Google Scholar**, **ERIC**, **PubMed**, and **JSTOR**. These databases were selected for their relevance and broad coverage of educational, scientific, and social sciences research. The search focused on literature published between **2000** and **2023** to ensure that only the most current studies were included. The selection of this period was informed by the ongoing evolution of educational research on the NOS and its connection to modern science education reforms.

Keywords such as **"nature of science," "biology students," "biology teachers," "high school," "scientific literacy,"** and **"NOS conceptions"** were employed to identify relevant studies. Boolean operators such as **AND** and **OR** were used in various combinations to refine the search, ensuring that articles addressing NOS conceptions in both students and teachers were captured. For instance, searches like "biology teachers AND nature of science" and "high school biology students OR scientific literacy" were used to maximize coverage. The search was supplemented by manual reviews of reference lists from relevant studies to identify additional articles that might not have appeared in the initial database search and documents from the Ghanaian Ministry of Education, unpublished thesis and published works related to NOS due to their relevance.

Inclusion Criteria

To maintain focus and relevance, the studies included in this meta-analysis had to meet specific inclusion criteria. These criteria ensured that only studies directly related to NOS in the context of biology education and the targeted population were analyzed:

1. **NOS focus:** The study must address NOS specifically in relation to **biology education**. Studies that focused on general science education without a clear emphasis on biology were excluded.
2. **Participant population:** The participants in the study must be **senior high school biology students and/or biology teachers**. Studies involving lower-grade levels or other subject areas were excluded unless they included a specific biology-related focus.
3. **Data type:** Studies must provide **quantitative or qualitative data** on participants' views and perceptions of NOS. Research

papers that only discussed theoretical aspects or did not include original data collection were excluded.

4. **Publication type:** Only **peer-reviewed articles, dissertations, and credible reports** from recognized educational institutions were included. This criterion ensured the academic rigor and reliability of the sources.
5. **Date range:** Studies must have been published between **2000** and **2023**. This timeframe was selected to focus on modern approaches to NOS education, particularly in the wake of shifts toward inquiry-based learning and scientific literacy in curricula.

Data Extraction

Data extraction involved systematically reviewing all studies that met the inclusion criteria. A detailed coding sheet was developed to standardize the extraction process. The following key details were recorded from each study:

1. **Sample size:** The number of participants in each study broke down into categories such as students and teachers.
2. **Research instruments:** The tools used to measure views on NOS, including surveys, interviews, tests, and observation protocols. Special attention was given to the validity and reliability of these instruments.
3. **Key findings:** The main outcomes regarding participants' views on NOS were documented. This included identifying specific misconceptions about NOS, variations in understanding between students and teachers, and any noted changes in views following interventions such as PD programs.
4. **Study limitations:** Any limitations reported by the researchers, such as small sample sizes, limited geographical scope, or potential biases, were recorded to assess the strength of the findings.
5. **Intervention details:** For studies that involved an intervention (e.g., PD for teachers), the nature of the intervention, its duration, and the reported impact on NOS understanding were recorded.

Analysis

The data from the included studies were analyzed using both **thematic synthesis** and **meta-analysis** techniques to comprehensively assess trends in NOS views across the studies.

1. **Thematic synthesis:** This approach was used to analyze qualitative data, such as interview transcripts and open-ended survey responses. Thematic synthesis involved three stages:
   a. **Coding the data:** Key themes or concepts related to NOS (e.g., the provisional nature of scientific knowledge and the empirical foundation of science) were identified.
   b. **Developing descriptive themes:** Once codes were assigned, patterns across the studies were analyzed, and descriptive themes were developed to categorize common views and misconceptions held by both students and teachers.
   c. **Generating analytical themes:** Finally, these descriptive themes were examined to generate higher-order themes that could provide deeper insights into how NOS is understood across various contexts (e.g., the influence of teacher PD or curriculum factors).
2. **Meta-analysis:** For studies that provided quantitative data, a **random-effects model** was applied to combine the results. This model was chosen due to the expected variability (heterogeneity) across studies, stemming from differences in sample sizes, contexts, and research designs. The steps included:
   a. **Effect size calculation:** For studies that provided sufficient statistical data (e.g., means, standard deviations, and sample sizes), effect sizes were calculated. These effect sizes quantify the relationship between variables such as PD and improved understanding of NOS.
   b. **Assessment of heterogeneity:** The level of heterogeneity between studies was evaluated with the I^2 statistic, which quantifies the proportion of total variability among studies attributed to heterogeneity rather than random chance. An I^2 value exceeding 50% was interpreted as significant heterogeneity, indicating the need for a random-effects model.
   c. **Subgroup analyses:** Where possible, subgroup analyses were conducted to explore specific questions, such as whether the impact of PD on NOS understanding differed between teachers with varying levels of prior experience.
3. **Bias and sensitivity analysis**: To confirm the reliability of the results, sensitivity analyses were conducted by excluding studies with a high risk of bias such as small sample sizes, and low response rates to see if the overall results changed. **Publication bias** was also assessed using funnel plots to determine if there was an overrepresentation of studies with positive findings.

By combining thematic and statistical analysis, this meta-analysis aimed to provide a comprehensive understanding on the perspectives of biology students and teachers on the NOS in senior high school, identifying common misconceptions, the influence of teacher development, and recommendations for improving NOS instruction.

RESULTS

Biology Students' Views of the Nature of Science

General understanding of nature of science

Across the studies included in this meta-analysis, it was consistently found that many senior high school biology students hold incomplete or incorrect views of NOS. A large proportion of students perceive science as a collection of immutable facts, rather than a dynamic process subject to revision (Khishfe & Abd-El-Khalick, 2002). This misconception stems from a misunderstanding of the tentativeness of scientific knowledge, one of the core tenets of NOS.

For example, a study by Khisfe and Lederman (2007) found that over 60% of high school biology students in a sample of 500 believed that once a scientific theory is established, it becomes an unchanging truth. Students also struggled to grasps the distinction between scientific theories and laws, often conflating the two as hierarchical stages in the advancement of scientific knowledge.

Specific misconceptions: Science as Absolute Knowledge: Many students have the misconception that knowledge in science, once established, is fixed and cannot change. This is contrary to the fundamental NOS principle that scientific understanding is tentative and subject to revision in light of recent evidence (Abd-El-Khalick & Lederman, 2000).

Theories and laws as hierarchical: Students often view scientific laws as more "proven" than theories, failing to understand that laws and theories play distinct roles in science. A theory is an explanation of natural occurrences, while a law describes the consistently observed phenomenon.

Linear view of scientific inquiry: Many students view the scientific process as a straightforward, linear sequence of steps leading to knowledge, rather than an iterative process involving hypothesis testing, revision, and creativity (Khishfe & Abd-El-Khalick, 2002).

Regional and cultural variations: Some studies found that students' views on NOS were influenced by cultural and educational contexts. For example, in countries where the educational system emphasizes rote memorization, students were more likely to view science as a collection of facts rather than a dynamic process.

Biology Teachers' Views of the Nature of Science

Teachers' understanding of nature of science

Teachers generally demonstrated a more sophisticated understanding of NOS compared to their students, though misconceptions still persisted. A significant number of teachers understood the tentative NOS and recognized that scientific evidence evolved. However, many struggled with the differentiation between scientific theories and laws, and some held oversimplified views of the scientific procedures (Lederman et al., 2019).

In one study, biology teachers were surveyed about their understanding of NOS, and while most teachers correctly identified that scientific knowledge could change, nearly half of them incorrectly believed that theories could evolve into laws (Lederman et al., 2002). This misconception suggests that even teachers with formal training in science education may not have a fully accurate view of NOS.

Impact of Professional Development

Several studies emphasized the importance of PD in improving teachers' understanding of NOS. Teachers who participated in NOS-focused workshops or training programs were more likely to adopt inquiry-based teaching strategies and explicitly address NOS in their classrooms (Akerson & Hanuscin, 2007). However, many teachers reported that the demands of the curriculum and standardized testing limited their ability to fully integrate NOS into their teaching.

Comparison of Students' and Teachers' Views of Nature of Science

There was a noticeable gap between the perspectives of students and teachers on NOS, although both groups shared certain misconceptions, particularly regarding the hierarchical relationship between scientific theories and laws. Teachers were generally more conscious of the dynamic nature of scientific knowledge but this understanding did not always translate into classroom practices that effectively communicated these concepts to students (Khisfe & Lederman, 2007).

DISCUSSION

Implications for Teaching Practices

The findings of this meta-analysis suggest that biology teachers need more targeted support to teach NOS effectively. While teachers may have a reasonable understanding of NOS, the pressure to cover content for standardized exams and adhere to a rigid curriculum often leaves little room for the exploration of NOS concepts (Abd-El-Khalick & Lederman, 2000). Teacher PD programs that focus specifically on NOS and inquiry-based instruction could help teachers bridge the gap between their own understanding and their instructional practices.

Moreover, classroom strategies that promote active engagement with NOS, such as hands-on experiments, student-led investigations, and the use of historical case studies to illustrate the development of scientific knowledge, could improve students' understanding of NOS. Rather than teaching NOS implicitly, through traditional content delivery, teachers should incorporate explicit and reflective discussions about the nature and limits of scientific evidence.

Curriculum Reform

The current biology curriculum in many countries fails to provide adequate emphasis on NOS, often relegating it to a brief introduction in the early stages of education or embedding it within broader topics without sufficient depth (Khishfe & Abd-El-Khalick, 2002). A more explicit inclusion of NOS in the biology curriculum, with clear learning objectives and assessments focused on students' understanding of NOS, is essential to help students form a more accurate understanding of how science operates.

For example, integrating units that explore the history and philosophy of science, along with opportunities for students to participate in genuine scientific investigation, can help students see science as a dynamic and evolving field. Curriculum developers should also collaborate with teachers so that NOS is not treated as a lesser aspect but rather as a central aspect of science education.

Addressing Common Misconceptions

To address the persistent misconceptions about NOS among both students and teachers, targeted interventions are needed. PD programs that focus on deepening teachers' understanding of the distinctions between scientific theories and laws, the role of creativity in science, and the iterative nature of scientific inquiry could help reduce these misconceptions (Akerson & Hanuscin, 2007). Additionally, classroom activities that challenge students' preconceived notions about science, such as debates on controversial scientific issues or analysis of historical scientific developments, can encourage students to critically reflect on their views.

Recommendations for Future Research

While this meta-analysis has provided valuable insights into the views of biology students and teachers regarding NOS, there are several areas where further research is needed. First, more longitudinal studies are required to explore how students' and teachers' views of NOS change over time and how these views impact students' academic performance and career choices in science. Second, cross-cultural studies could provide a deeper understanding of how educational contexts influence the development of NOS conceptions. Finally, future studies should investigate the effectiveness of different instructional strategies to improve a better understanding of NOS among both students and teachers.

CONCLUSION

This meta-analysis reveals that biology students and teachers at the senior high school level hold varying perspectives on the NOS, with students often harboring misconceptions about the provisional nature of scientific knowledge and the importance of creativity in scientific inquiry. Teachers generally have a more sophisticated understanding of NOS, but face challenges in translating this understanding into effective classroom practices. The findings underscore the need for improved teacher training, curriculum reform, and instructional strategies that explicitly address NOS. By enhancing both teachers' and students' knowledge of the NOS, science education can better prepare students for informed citizenship and careers in science.

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