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REVIEW ARTICLE

Didactic Handout on Nature of Science: Toward Effective Teaching of Physical Science Curriculum

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ABSTRACT

The decision to integrate Nature of Science into classroom practice is no longer a debate among science educators and curriculum experts. There exists empirical evidence to substantiate its effectiveness, judging by both the academic performance and ability of students to conceptualize abstract yet teachable areas in science. Curriculum and Assessment Policy Statement of physical science permits for teachers, fundamentally, the discretion to inculcate and incorporate Nature of Science in classroom practices. However, the usual classroom practices are far from the expectations of both curriculum experts and policy makers in the field of science education. Ambiguity, accessibility, and perceived non-domestication were three areas identified in the literature to be responsible for lack of integration aside capacity building. This manuscript provided answers to the three areas of need by traversing relevant literature on both Nature of Science and Science education with a view to aggregate and simplifies scholarly positions for easy classroom usage for teachers and educators alike. Positions were drawn from nature of science, attendant curriculum, and position of literature with respect to the locale. Literature reviewed in this manuscript avail reader's inherent conditioning and grit to understand nature of science and its essence in science teaching and learning.

KEY WORDS: Science education; nature of science; physical sciences; science curriculum

INTRODUCTION

Science has historical links with some elements of philosophy (Laplane et al., 2019; Neyman, 1957; Ruse and Wilson, 1986; Søvik, 2022). How science is done, learnt, and documented is still evolving. This evolution begets a consistent pattern. This pattern forms the culture of science (Nouri and McComas, 20019). This culture is transferred along with the elements of science to the extent that when science is done, these elements are inherent. Such inherent elements become the Nature of Science (NOS) (Nouri et al., 2021; Wahbeh and Abd-El-Khalick, 2014).

Experimentation and observation are key elements of science. Experimenting changes in the features and characteristics of a subject under certain conditions describes science. Furthermore, observation and documentation of these changes are also peculiar to science. Science is done by scientist. The previous statement may not be necessary as it sounds too narrow. However, what do scientist do? The answer will be - science. Interchanging these two narratives will only make meaning by understanding science and scientist. The study of facts learned through experimentation and observation may mean science. Furthermore, investigating, understanding, and explaining natural, physical world and the wider universe defines science and how it is done. The rest of the paragraphs will simplify the aforementioned positions for clarity.

Science describes the natural world (the universe, component, and constituents) based on facts (empirical evidence) learned through experimentation (tentative procedure) and observation (occurrence that involves recording for inference) of phenomenon - scientific event (Abimbola and Omosewo, 2006; McComas, 1998; Merriam Webster Online Dictionary, 2022). This evidentially explains science as factual knowledge - evidential and not belief. The purpose of doing science is to create, generate, and/or improve knowledge. The knowledge generated is not absolute, as it contradicts the character of science (nature), rather, tentative explanation, and presentation of facts based on the knowledge available at the time of experiment and observations (Nouri et al., 2021; Nouri and McComas, 2019). Science by nature perceive imagination as a way of thinking through inductive and deductive patterns (Lederman, 2007; McComas, 2019). Science Education literature over the years have brought to the consciousness of teachers, learners, and experts, established norms in science through NOS (Abd-El-Khalick, 2013; Mesci, 2020). Scientific knowledge is constructed, assessed, and verified before being communicated to a larger audience. While there are established procedures in science, it is not in any way a form of indoctrination, rather, a relatable practice devoid of dogma (Lederman, 2007; Mathews, 2014). In effect, science in itself is testable, verifiable, and can be questioned at every stage of its acquisition (Lederman, 2007; Osborne et al., 2003).

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Science is the belief in the novice experience of experts whose limited knowledge is embraced based on momentary presentation of facts - tentativeness is rudimentary to science (Lederman, 1999, 2007). No science is static, rather temporarily stable under categorizable conditions. An historical account justifies history as a major component of science and its teaching, this suggests that science evolved based on available knowledge at the disposal of individuals (not only experts) and the society - underscoring the place of culture (Bagdonas and Silva, 2015; Lin and Chen, 2002; Nouri and McComas, 2019). As evident in new emerging fields, non-existent many decades before now, new knowledge brings about a new perspective which eventually changes the inner-workings and outlook in effect about an old way of doing science (Abd-El-Khalick, 1999; Rudge et al., 2014). The disciplinary norms in science are explainable, most of which share rudimentary prescriptions like other fields of knowledge (McComas, 1998). Fundamentally, doing science is continuous and its knowledge motional, its teaching and learning requires not only content and pedagogical knowledge, but also expertise in its history and nature (Rudge et al., 2014; Wheeler et al., 2019).

For science learners, there are ethical and disciplinary basis on which the knowledge of science should be built (Wicaksono et al., 2018). To science educators and philosophers of science, the way science is taught and the conditions surrounding its teaching remains a subject of debate in the parlance of literature to date (McComas, 1998; Schizas and Psillos, 2019). Some of the debates arising from literature are: What stage should NOS be introduced to the students? - scholars argue for NOS to be taught both implicitly and explicitly at the most elementary stage of schooling (AAAS, 2009; McComas and Clough, 2020; Sweeney and McComas, 2022). What part of NOS should be introduced to the learners? – reflections on this aspect had been investigated by authors and associations alike (Lederman, 2007; McComas, 2004, 2019; NSTA, 2020). Should NOS be taught independently as a subject? Akerson et al. (2010), Le Grange (2007), and Murphy et al. (2019) have all posited in this direction. Should NOS be integrated into the History of Science (HOS) and science teaching along with content knowledge? – questions have been raised and answered in this direction (Abd-El-Khalick and Lederman, 2000; de Hosson and Décamp, 2014; Nouri and McComas, 2019). These are among other legitimate concerns of educators, curriculum experts, and policy makers globally on NOS and its integrations. The position of historians, sociologist, and philosophers of science are that science should be perceived as an entity and its nature should be taught separately from the cradle. This brings to the fore debates on implicit and explicit approach to NOS integration (Lederman, 2007; Mesci and Cobern, 2020; Mesci and Schwartz, 2017).

THE NATURE OF SCIENCE

Considering the emergence and the perspectives of researchers in science education on Nature of Science (NOS), various components have been investigated. Teaching, learning, level of integration, implicit and explicit approaches have been researched by science educators (McComas and Clough, 2020). What definition should be acceptable or appropriate will be context dependent. However, from theory and the nature of knowledge, with respect to acceptable limit and validity, NOS is considered as the ethics (responsibility) of scientist in doing science (scientific research) with a view to improve scientific knowledge (Abd-El-Khalick, 2013; Lederman, 2007; McComas, 2004). The understanding of how the knowledge of science is been produced putting into consideration basic components of science and its eventual impact on the society is an accessory to NOS (Clough, 2006; McComas and Clough, 2020). Simply put, NOS is evidence based, methodical, sociocultural, creative activity of scientists, established in how knowledge of science is been generated, taking into cognizance the evolution (history) of scientific knowledge (Lederman, 2007; McComas, 2019; Nouri and McComas, 2019, Osborne et al., 2003). Bypassing the complexity and ambiguity in literature for the sake of non-experts, the need to pass down the knowledge of science for generality, continuity, and evolution exposes the rationale for NOS in science education. Science had been previously defined to suit the context of this manuscript in the earlier paragraphs. Education, here, refers to a field of knowledge concerned with the methods of teaching and learning-pedagogy.

The need to form an encompassing understanding of scientific discipline irrespective of various component fields makes NOS imperative. Scientific knowledge in effect is reliable, yet, tentative. The tentativeness here abrogates permanence, that is, the position of scientific knowledge can change as a result of a new knowledge - evidence-based (Nouri and McComas, 2019). Similarly, NOS is subjective to human observations, imagination (possesses theoretical basis), and creative ability (Akerson et al., 2019). NOS expose the empirical dimension of the knowledge of science through concordant evidence from observation and experimentation of the natural world (Nouri and McComas, 2019). Furthermore, cultural influence has a place in NOS – the society in which science would be practiced must impact the direction of research (Nouri et al., 2021; Sweeney and McComas, 2022). With NOS, scientific theories and laws have different bases for establishment, yet, significant at each instance. NOS view science process and knowledge as multi-dimensional with no absoluteness – negates the single method fallacy as perceived by learners (Abd-El-Khalick, 2013; Abd-El-Khalick and Lederman, 1999; Lederman, 2007). Due to the afore-explained, researchers have argued against the possibility of arrogating these components (historical, philosophical, and sociological aspects of science) into the teaching of science without a conscious pronouncement in the curriculum for learners at various levels (Cansiz, 2019; Walls et al., 2013). Developing nations have these components in the curriculum but face challenges in the implementation with respect to technical know-how, although can be remediated through capacity building (Le Grange, 2007, Rudge et al., 2014; Sahin and Deniz, 2016).

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Explicit approach to NOS teaching in the classroom is dated in the literature (Olsen, 2018). Scholars have assented for and against this position (Akerson et al., 2019; Murphy et al., 2019). While authors have established reasons to integrate NOS into science teaching, others argued for it to remain in the consciousness and not as co-component of science teaching (Lederman, 1999; Schwartz et al., 2004). A number of scholars have provided an empirical basis for classroom integration of NOS positing that learners do not automatically acclimatize with the epistemology of science through formal classroom engagement in the subject matter, rather, a conscious attempt must be made by teachers to establish it in the mind of learners through history and sociocultural perspectives (Akerson et al., 2010; Bell et al., 2000; Schwartz and Lederman, 2002). Proponents of the explicit approach have submitted that, aspects of NOS should be built into classroom activities; however, this is not to say that it should be didactical or directly taught (Nouri et al., 2021; Nouri and McComas, 2019; Sweeney and McComas, 2022). NOS should be reflective - reflect potential structure to guide learners in self-examination of science leaning within agreeable framework (Abd-El-Khalick, 2013; Cansiz, 2019; Maramante, 2018).

An explicit/reflective approach is favored by emerging literature to improve students' scientific literacy and conceptualization of science. A background linkage of NOS activity is expected in effect for explicit/reflective approach. Each appendage of the classroom activities has an historical account to justify the part of science being taught (McComas and Clough, 2020; Nouri and McComas, 2019; Nouri et al., 2021). Akerson et al. (2019) posited that scientific methods of inquiry, activity/guide discovery, and discussion methods should afford NOS components in contextualized and decontextualized forms at elementary stage and beyond. Sweeney and McComas (2022) stratified NOS into teachable components of inferential, empirical, creative, collaborative, tentative, and cultural. The authors furthered that there is no single order in terms of scientific method, as such, teachers are expected to be discretionary in terms adaption in their classrooms. Teachers of science are saddled with the responsibility of checking appropriate approach that most benefit their learners (Nouri et al., 2021).

In effect, contextualized scenario expose learners to instance/s in history of science which supports classroom activity at the time of usage on nature of science. Conversely, decontextualized scenario exposes history of science not necessarily/particularly related to classroom event but also supports students learning of NOS. In spite of over half a decade scholarly documentation of the need to incorporate NOS into classroom teaching, many teachers of science are yet to sufficiently put it into their practices due to ambiguity in the literature available and limited capacity in terms of application (Capps and Crawford, 2013). Instructors/teachers who attempt the teaching of NOS at all, have been reported to explore implicit approach which is inadequate with respect to students' conceptualization and effective learning in science for the inaccessibility of content on explicit approach (Kruse et al., 2019).

Summarily, aside approaches recommended in NOS integration, it is also imperative to discuss its various aspects which expectedly should provide guidance to its domestication. The empirical and inferential nature of science explains the scientific evidence presented as a result of observation. In this instance, inferences are drawn based on a trend of controlled events. Usually, the essence in this instance is to create a model when there is no physical or/and limited representation of such scenario. Tentative nature of scientific knowledge holds the view that scientific theories remain unchanged until a superior position is tendered. Within the gamut of science and science education, developers of curriculum coin generally acceptable content, policy, and direction of practice to bridge the gap between science and science teaching.

NATIONAL CURRICULUM STATEMENT FOR PHYSICAL SCIENCES

The National Curriculum Statement (NCS) is a Curriculum and Assessment Policy Statement (CAPS) which originated from the Department of Basic education (DBE), Republic of South Africa. Historically, an outcomes-based education was introduced to shift paradigm from curricular division post-apartheid in 1997. A review of this document was done in the year 2000. This curriculum revision was called the Revised National Curriculum Statement for all grades including grades R-9 and the National Curriculum Grades 10-12 (DBE, 2011). Subsequently, challenges of implementation necessitated another revision in 2009 to produce two National Curriculum Statements for Grades R-9 and 10-12. These two documents were later merged to form a single document publicly referred to as the National Curriculum Statement for Grades R-12 in 2011. To date, this document represents a policy statement for teaching and learning of various subjects in South African schools (DBE, 2011, 2021a).

Similarly, the new NCS grades R-12 houses three of the most important documents at these levels. These documents are the Curriculum and Assessment Policy Statement (CAPS) for all approved subjects; the National policy pertaining to the program and promotion requirement of teachers in the National Curriculum Statement Grades R-12; and the National Protocol for Assessment Grades R-12. All subjects at this level now have a single and comprehensive CAPS that replaced the old subject specific statements. The aims of the curriculum among others are to ensure that learners acquire and apply knowledge and skill in meaningful ways. These acquisition and application of knowledge, and skills formed one of the core reasons for NOS. Furthermore, the curriculum is to facilitate the transition of learners to higher education, and for others, to their workplace. For physical sciences - chemistry and physics components are embedded. The transition becomes imperative as STEM careers ultimately require creditable performance in this subject for future relevance. The curriculum also fosters

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critical thinking approach to learning which in this case has its foundational component in NOS (DBE, 2011, 2021b).

Nature of Science is a component of the NCS Grade R-12. For example, from section 2.2 “the construction and application of scientific and technological knowledge; an understanding of the NATURE OF SCIENCE and its relationships to technology, society, and the environment” (DBE, 2012, p. 8). Underplaying the role of NOS in science teaching has no place in the National Curriculum Statement Grade R-12. However, the decision of teachers and educators to incorporate NOS in their teaching remains a valid question in South Africa. Moreover, the capacity of the teachers in terms of integration is also valid and remains outside the purview of this manuscript. However, decongesting ambiguity, aggregating meaningful literature for accessibility, and relating NOS in the local context are herewith. There are six knowledge areas/topics which informed the Physical Science section of the curriculum. They are Matter and Materials; Chemical Systems; Chemical Change; Mechanics; Waves, Sound and Light and; Electricity and Magnetism (DBE, 2012). The sub-knowledge areas/sub-topics are available for general inclusion in the curriculum and assessment policy statement (CAPS) (DBE, 2011).

A non-expert breakdown would be that physical sciences comprise two main subject areas, namely, physics and chemistry. For clarity, the physics and chemistry components of the physical sciences curriculum are taught independently at separate terms as indicated in the link provided in the preceding paragraph. As stipulated, the application of each of the components is done at all cognitive levels in all the knowledge areas which is further examined by the assessment taxonomy at cognitive levels (1-4), embedded link CAPS. In view of the position of the curriculum, it becomes imperative for learners to be taught the rudiment and rigor of problem solving, indulge in practical activities, and must be tested in all areas that are afore listed. Furthermore, there are informal assessment methods of classwork, practical experiments, homework, and informal tests as enshrined in CAPS. This section of the manuscript provides a filtered overview for experts and non-experts with regard to NCS Grade R-12. However, the subsequent section will avail readers the position of literature on NOS within South Africa.

POSITION OF LITERATURE ON NOS

NOS in science instruction has been reviewed to expose technical rudiments to instructors of science. Investigation was done by Sweeney and McComas (2022) for K-4 science teachers teaching students between the ages of 5-9 years in the United States. The study was informed by the need to introduce children early to science curriculum. Elementary teachers’ perception of the developmental appropriateness of aspects of NOS in the school years formed the focus of the study. Binary logistic regression was employed in the analysis of data on teachers’ introduction of NOS as predictor of perception of developmental appropriateness among 377 sampled respondents. In the study, developmental appropriateness was significant in predicting teachers’ self-reported introduction for nine of the 12 components of NOS under investigation. The implication of this study is that NOS should be introduced to learners as early as possible to improve learners’ creativity and conceptualization of science concepts.

Proposed teacher competencies to support effective nature of science instruction was studied through a meta-synthesis lens. Nouri et al. (2021) explored systematically existing literature on teacher competence in teaching NOS from 2009 to 2018. A framework was developed using 58 peer reviewed articles on proposed competencies for what teachers need to know to be effective instructors. The outcome elicited 20 specific competencies found in seven categories considered necessary in support of effective NOS instruction from NOS specific to pedagogical elements. These elements were NOS knowledge, content knowledge, learners’ knowledge of NOS, instructional strategies knowledge, assessment of NOS knowledge, pedagogical knowledge and motivation, and beliefs about NOS. From the afore listed, a guide was produced to serve as template which guides educators in preparing teachers to demonstrate competencies in NOS and improve the quality and depth of learners (Nouri et al., 2021).

In another related study, Nouri and McComas (2019) researched the history of science as a vehicle to communicate aspects of the nature of science. Their study examined the perception of history of science instructors on nature of science. Data of 15 instructor and 11 institutions teaching history of science in class as part of mathematics and science teacher preparation program. The study found that there were various aspects of NOS which instructors emphasized along with history of science goals accompanied by different approaches which included NOS. A number of instructors believed that NOS should be the focus of history of science during instruction and that it should be explicitly taught. The implication is that preservice teachers should learn NOS as inherent in history of science class. By extension, teachers/instructors of science are at liberty to either approach science teaching from the history of science to nature of science or the other way around with the focus being learners and quality instruction.

POSITION OF LITERATURE ON NOS IN SOUTH AFRICA

There are several perspectives to doing science as argued in the literature. A number of science educators view science as local and cultural while many argued the alternative of universality in terms of approach. This section highlights some of the research studies in the field of science education, science education curriculum and policy, as well as Nature of Science in the South African context.

Olivier and Kruger (2022) provided an exposition into science education in South Africa. Economic, cultural, and technological development experienced was adduced in the

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study to colonial and apartheid influence which had trickled down to the wider education systems. An historical exposition of both school and post-school sectors from the lenses of governmental structure and national framework distinguished the study. General and science-based statistics were employed to justify educational output at different levels. Extensive discussions were done with respect to science education, curriculum policy, students' assessment, and teachers' training, as well as integration of technologies for classroom practices in the manuscript.

Samuel et al. (2020) explored natural science teachers' pedagogical competence in teaching particulate nature of matter (PNM) in the Northwest Province of South Africa. The natural science teachers' pedagogical shift arising from teachers' professional development as captured in CAPS formed the direction of the study. Understanding the use of science in the teaching of PNM with theoretical foundation in Pedagogical Content Knowledge (PCK) constitute this study. A qualitative approach allowed for two purposively sampled teachers to participate with two adopted instruments of PCK test and semi-structured interview. The study reported a positive shift in PCK of the two respondents. The study also recommended that teachers' professional development as allude in CAPS be taken seriously to enhance the capacity of teachers for effective teaching of physical sciences.

Opoku and James (2021) examined the need for decolonization of curriculum of science education. With a qualitative approach of naturalistic type, the study explored Indigenous Knowledge (IK) holders of Zulu cultural group and Senior High School (SHS) teachers to provide answers to South African science classroom engagements. The methodology employed was the interpretivist, multi-site ethnographic and naturalistic style with interview as primary source of data from purposively selected respondents in the community. Thematic analysis of data was used to generate culturally moderated pedagogical model on how to teach indigenous knowledge in science classroom. The study concluded that the model is a useful tool for indigenous pedagogies, to demystify indigenous perceptions and practices, among others.

Erduran and Msimanga (2014) explored science curriculum in South Africa with a view to bring to the fore lessons for professional development in science education. In the article, the researchers put forward argumentation as route for inquiry in teaching and learning. They argued that an Indigenous Knowledge System (IKS) and the Nature of Science (NOS) are both relevant for argumentation. Argumentation as clarified in the study entails a coordinated attempt at presenting evidence and theory to refute or support a scientific conclusion. At the time, curriculum development in South Africa was reviewed with reference to IKS and NOS. Evidence was drawn from research and developments on argumentation for effective curriculum content implementation.

Ramatlapana and Makonye (2012) researched teachers' autonomy with respect to curriculum change from NCS to CAPS. As relayed by the authors, the NCS limitations were the justification for CAPS review, however, it was stressed that the new revised edition has compromised educators' freedom. Empirical case study of Further Education and Training (FET) implementation of CAPS were dissected to bring to light the extent of professional autonomy allotted to educators. The theory of planned behavior (TPB) which presumes that teachers' beliefs guide their activities in their classrooms was adopted in the study. A total of 52 educators from diverse subject areas from 12 schools in Johannesburg formed the respondents for primary data. The study among others concluded that, the prescriptive nature of CAPS compromises the autonomy of educators which in turn has negative implication on the quality of output expected in students' learning.

Adler et al. (2009) explored mathematics and science teachers' education in South Africa with a view to review research, policy, and practice. The study sampled studies done in South Africa between 2000 and 2006 with a view to report the pattern of research and proffer remedial solutions to the challenges of teaching mathematics and science. The researcher reported a pattern of significance in qualitative studies which were conducted mostly in urban areas among formal in-service teachers. Further to the afore mentioned, the paradigm of research shifted (in the period under review) to NOS, IKS, and science process skill development with emphasis on content knowledge. Specifically, mathematics and science content knowledge for the teaching and learning of mathematics with respect to curriculum reforms caught the attention of researchers over the period. Among others, the researchers recommended that more investigations should be directed at gaps identified in rural areas to alleviate the challenges encountered by teachers of mathematics and science for inclusivity.

Le Grange (2007) investigated western and indigenous knowledge integration for effective science education in South Africa. This non-empirical study extensively clarifies the western science from indigenous science through Jegede's theory of collateral learning. Disparate was employed in describing both western and indigenous science as both have distinct quality and characteristics which makes the two unique. While putting in perspective NOS, the researcher posited that science is representational at conceptual level. However, performance-based science is argued to be locally produced. The author concluded in the manuscript that, in South Africa, it is agreeable to compare disparate traditions of western and indigenous knowledge as equitable. This perspective substantiates the potential of avoiding cognitive dissonance when discussing science in the classroom.

CONCLUSION

The position of the curriculum is clear about the Nature of Science in science teaching and instruction. NOS components and the rationale for its integration hold position in literature

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to improved students' conceptualization and performance as highlighted in this manuscript. Its classroom practice by teachers to the benefit of the students is encouraged by the government of South Africa through the Department of Basic Education (DBE, 2011). Policy statements which provide further guidance on the implementation of the curriculum for support is available (DBE, 2021a). Government regulations regarding the scope, requirements, conducts, and concessions also provide a template for educators in this direction (DBE, 2021b). Bulk of the responsibility resides with teachers to ascertain qualitative integration for learners to excel at both internal and external examinations. The assessment mechanisms to moderate and guide classroom practices for effective and efficient classroom delivery are in the fore. The onus is for educators of science to get accustomed with the implementation of the curriculum and considering NOS as not only an appendage but also testable route for learners to conceptualize science.

ETHICAL STATEMENT

The authors posit that no ethical issues were violated in this Manuscript. There are no direct human participants in this study, as such; no primary data were collected from respondents which may have required consent. The curriculum and policy documents employed in this study are public documents which require no authorization at the time of publishing this manuscript.

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