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IMPROVING THE RELEVANCE OF SCIENCE EDUCATION CURRICULUM BY INTEGRATING THE NATURE OF SCIENCE, SCIENCE AND ENGINEERING PRACTICES, AND INDIGENOUS KNOWLEDGE IN AFRICA

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A B S T R A C T

Many African countries have emphasized science and technology as the engine for national development. Hence, they have made core science subjects (Chemistry, Biology, Physics and Mathematics) to be compulsory in high school. However, learners' interest in studying science has not increased, and they have continued to perform poorly in these core science subjects. Most researchers have argued that the science taught in schools at all levels of education is irrelevant to the learners' needs and out of context. Also, the current science is taught as a fixed knowledge in a dogmatic style without considering the Nature of Science (NOS) in the real world. Therefore, in this paper, the researcher proposes based on the literature review how we should integrate the NOS, Science and Engineering practices, and Indigenous knowledge to improve the relevance of science education curriculum at all levels of education (from Preprimary to University). This will help the African countries to train a critical human resource in Science, Technology, Engineering and Mathematics (STEM) fields to solve the problems facing humanity accordingly.

1. Introduction

The education system of any country is the mother of all skilled labor force in STEM fields. Thus, there is no country that can develop without investing in science and technology education. Hence, many African countries have emphasized science and technology as the engine for national development, and have therefore made core science subjects (chemistry, Biology, Physics and Mathematics) compulsory at high school. However, learners' interest in studying science has not increased, and they have continued to perform poorly in these core science subjects. Most researchers have argued that the science taught in schools at all levels of education is irrelevant to the learners' needs and out of context. Also, the current science is taught as a fixed knowledge in a dogmatic style without considering the Nature of Science (NOS) in the real world. Hence, it is important for curriculum developers in African countries to rethink the current science curriculum by making it relevant to the learners' problem. This will go a long way to help learners become creative and innovative in generating solutions facing humanity. In this paper, I describe the concept of nature of science (NOS) as well as Science & Engineering practices and indigenous knowledge. I then suggest strategies to integrate these concepts at all levels of science curriculum (Pre-primary to University), to improve the relevance of science Education in Africa.

2. The nature of science

The construct, “nature of science” (NOS), has been advocated as an important goal for studying science for more than 100 years (Central Association for Science and Mathematics Teachers, 1907). NOS is the epistemology of science underlying the practices embedded in investigations, field studies, and experiments, the values, and beliefs inherent to the scientific enterprise, and the development of scientific knowledge (Abd-El-Khalick, 2013). According to the Next Generation Science Standards (NGSS, 2013), there are eight tenets of NOS understanding students should learn in the classroom, namely:
(1) Scientific investigations use a variety of methods, (2) Scientific knowledge is based on empirical evidence, (3) Scientific knowledge is open to revision in light of new evidence, (4) Scientific models, laws, mechanisms, and theories explain natural phenomenon, (5) Science is a way of knowing, (6) Scientific knowledge assumes order and consistency in natural systems, (7) Science is human endeavour, and (8) Science addresses questions about the natural and material world. (NGSS Lead States. p. 16)

Discussions about what ideas should be considered under the rubric of NOS often include concerns about the list of the tenets above. Some scholars worry that the list of NOS aspects ends as “mantras” for students to memorize and repeat (Matthews, 2012, p. 68). Other scholars (Allchin, 2011; Clough & Olson, 2008; Irzik & Nola, 2011; Wong & Hodson, 2009, 2010) think the list provides too simplistic a view of NOS. However, the list serves as an important function, as it helps to provide a concise organization of the often-complex ideas and concepts it includes (Abd-El-Khalick, 2013). Irzik and Nola (2011) produced a depiction of NOS that they claimed is much more informative and comprehensive than the list. However, what they presented is basically the same as the list but formatted in a matrix instead of the list's linear format.

Due to the critical role science teachers play in developing learners’ NOS understanding, there has been a lot of research to assess and improve science teachers’ NOS understanding since 1950 (Clough & Olson, 2008). Most of the early research studies in the 20th century utilized the quantitative approach (closed instruments) to assess science teachers’ NOS understanding (e.g., Aikenhead, 1974; Ogunniyi, 1982; Pomeroy, 1993; Welch, 1966; Wilson, 1954). However, researchers in the 21st century are utilizing both quantitative and qualitative approaches to assess science teachers' NOS understanding (e.g., Bartos & Lederman, 2014; Wahbeh & Abd-El-Khalick, 2014). The two main approaches used by science educators to improve science teachers' NOS understanding are the (1*) implicit approach,* which suggests that an understanding of NOS is a learning outcome that can be facilitated through process skills in instruction, science content course work and doing science, and (2) *explicit approach*, which suggests that understanding of NOS can be increased if learners are provided with opportunities to reflect on their experiences (Abd-El-Khalick & Lederman, 2000). There is an ongoing debate among scholars about which of the two approaches is more effective.

What are the strategies to integrate NOS in science curricula/lessons?

Nature of Science Activities

- ❖ The science teachers should be engaged in ten different activities that explicitly address the eight-target aspect of NOS. A detailed description of these activities can be found in Lederman & Abd-El-Khalick (1998).
- ❖ Two of these activities address the function of, and the relationship between, scientific theories and laws. Two of the other activities ("Trick tracks" and "The whole picture") address the difference between observation and inferences, and the empirical, creative, imaginative, and tentative nature of scientific knowledge. Examples from specific science subjects (chemistry, biology, physics, Geology, etc.) should be cited to emphasize the tentativeness of scientific knowledge during the activities.
- ❖ The four other activities ("The ageing president," "That is part of life!" "Young? Old?" and Rabbit? Duck?") Target the theory of landenness and social and cultural embeddedness of science. Here also some examples from chemistry will be highlighted during the discussion to emphasize the influence of society on the development of chemistry knowledge (e.g., the discovery of artificial colour/dyes in Germany was highly facilitated by the need for the German military to manufacture the military uniforms).

  Finally, the two black box activities ("The tube" and "The cubes") should be used to reinforce participants' understanding of the above NOS aspects. Also, during the discussion, examples from specific science subjects should be highlighted during the discussion. Once the teacher trainees/teachers understand the NOS, they are expected to engage their learners with the same NOS activities when teaching science in their classrooms. This will improve the relevance and interest of learners in Africa to study science accordingly.

How can we teach the nature of science?

Students need to experience specific activities designed to highlight aspects of the nature of science. Inquiry activities, socio-scientific issues, and episodes from the history of science can all be used effectively as contexts in which to introduce and reinforce the nature of science concepts. We should help learners develop the NOS characteristics by engaging them in learning experiences related to their contexts. These include objectivity, verifiability, ethical neutrality, systematic exploration, reliability, precision, accuracy, and abstractness.

3. Science and Engineering Practices

A historical view of inquiry in science classrooms reveals three phases—learners doing inquiry, learners learning core science concepts through inquiry, and learners learning the nature of a scientist's inquiry (Sadeh & Zion, 2009). As we entered the 21st century, Anderson (2007) proposed there were three main areas of dilemmas that affected the implementation of inquiry: technical dilemmas, political dilemmas, and cultural dilemmas. Several researchers explored ways to ameliorate these situations (Atkins & Salter, 2014; Duschl, Schweingrubers, & Shouse, 2007; Hassan & Yarden, 2012; Miranda & Damico, 2015; Marshall & Smart, 2013; Lotter, Rushton & Singer, 2013; Saden & Zion, 2009). The most recent iteration of classroom inquiry in the US occurs in the new K-12 Framework (NRC, 2012) and Next Generation Science Standards (The NGSS Lead States, 2013).

Authors of the K-12 Framework addressed the inconsistencies of various views of inquiry in the past. In the K-12 Framework, the term "inquiry" appears only a few times, related to engaging students in doing inquiry, inquiry as a pedagogy or teaching about what scientists do (scientific inquiry). Striving to rebrand inquiry, the term "science practices" is used throughout the documents. Like the researchers and philosophers in the 20th century, authors of the 21st century K-12 Framework place emphasis on immersing children in the investigation as the centrepiece for learning science. The K-12 Framework strongly emphasizes that students experience, design and carry out investigations to learn about what scientists do, as well as the epistemology of science (NRC, 2012). "As in all inquiry-based approaches to science teaching, our expectation is that students will themselves engage in the practices and not merely learn about them secondhand," (NRC, 2012, p. 30).

As I review 21st-century science education from a historical perspective, the thirst to engage in science reminds me of ideas put forth by philosophers, curriculum developers, and educators of the past century. So, I may ask, what is different about the K-12 Framework and the NGSS of the term "science practices" compared with inquiry in the NSES "essential features"? Is this just another way to rethink what it means to teach science as inquiry? On the contrary, Osborne (2014) argued that inasmuch as the scientific practices in the K-12 Framework are remarkably similar to the list of the ability to inquiry in the NSES (1996), the difference lies in the greater clarity of goals about what students should experience, what students should learn, and an enhanced professional language for communicating meaning in the scientific practices than inquiry. The primary challenge in teaching science as inquiry has been a lack of common understanding of what real teaching science through inquiry is, and mixing doing science with the learning of science (Osborne, 2014). The K-12 Framework strongly emphasizes that students' experiences are designed and help them carry out investigations to learn about what scientists do and the epistemology of science (NRC, 2012).

In the introductory pages of the K-12 Framework (NRC, 2012) the first dimension, Science and Engineering Practices, includes: a) Asking questions (for science) and defining problems (for engineering), b) developing and using models, c) planning and carrying out investigations, d) analyzing and interpreting data, e) using mathematics and computational thinking, f) Constructing explanations (for science) and designing solutions (for engineering), g) engaging in arguments from evidence, and h) obtaining, evaluating and communicating information. A comparison of these practices with teaching inquiry in earlier reform documents in the US is shown in Table 1.

Table 1. A comparison of the abilities to do scientific inquiry (NRC, 1996, 2000) with the set of scientific practices found in the Framework for K-12 Science Education (NRC, 2012)

NSES (NRC, 1996, 2000): Essential feature of inquiry	K-12 Framework (NRC, 2012): Science, and Engineering practices
1. Identify questions that can be answered through scientific investigation.	1. Asking questions (for science) and defining problems (for engineering)
2. Design and conduct scientific investigations.	2. Planning and carrying out investigations
3. Use appropriate tools and techniques to gather, analyze, and interpret scientific data.	3. Analysing and interpreting data,
4. Develop descriptions, explanations, predictions, and models using evidence.	4. Developing and using models

5. Think critically and logically to make the relationship between evidence and explanations.	5. Engaging in arguments from evidence
6. Recognize and analyze alternative explanations and predictions.	6. Constructing explanations (for science) and designing solutions (for engineering),
7. Communicate scientific procedures and explanations	7. Obtaining, evaluating and communicating information
8. Use mathematics in all aspects of scientific inquiry.	8. Using mathematics and computational thinking

One distinguishing feature of the new K-12 Framework and NGSS is greater emphasis on scientific modeling and argumentation. The new documents propose a shift from simply having students form and test hypotheses to testing and revising theoretically grounded models. The idea involves students going beyond experiencing inquiry by interpreting and evaluating data as evidence to developing arguments, explanation, and models (Osborne, 2014). This emphasis on engaging in argumentation is not entirely a new one. For example, Abell, Anderson, and Chezem (2000) envisioned elementary teachers supporting children in learning science in this way: "The active quest for information and production of new ideas characterizes inquiry-based classrooms" (p. 65). Abell et al. (2000) recognized that although elementary classrooms may have moved beyond traditional instruction to hands-on instruction, this does not necessarily mean that it is inquiry instruction. Those authors described inquiry more than a decade ago as an argument and explanation. Additionally, the essential features of inquiry number 4 (Develop descriptions, explanations, predictions, and models using evidence) in Table 2 above emphasize modelling during inquiry-based learning. Hence, it seems that conceptually there is not a big difference between inquiry and science practices, except the emphasis on integrating science and engineering practices discussed below. However, studies to establish whether science teachers understand, and practice science practices better than inquiry should be conducted among the in-service science teachers who have experienced both in US contexts before we conclude that science practices are clearer than inquiry.

Another distinguishing feature of the K-12 and NGSS, as compared with historical writing about teaching science as inquiry, is the focus on *integration* (Osborne, 2014). The K-12 Framework emphasizes that learning science and engineering involves teachers providing students with the opportunity to learn about the "integration of the knowledge of scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design" (NRC, 2012, p. 11). The vision is that teachers design learning environments in a range of classrooms in which the notions of core science concepts, crosscutting concepts, and science practices are intertwined.

Osborne (2014) argued that inquiry failed because of a lack of common understanding of what was the real teaching of science through inquiry, and mixing doing science with learning science through inquiry. He asserted that the main goal of science education was to help students understand a body of existing consensually agreed and well-established old knowledge, but not to discover or create new scientific knowledge. He, therefore, encouraged science educators to move from inquiry to scientific practices because the scientific practices had a greater clarity of goals about what students should experience, what students should learn, and an enhanced professional language for communicating meaning than inquiry (Osborne, 2014). However, I do not entirely agree with Osborne (2014)'s argument that teaching science with inquiry failed because the approach mixed learning science with creating new scientific knowledge. This is mainly because, according to the constructivist theory of learning, learners are required to construct their scientific knowledge. In my view, Osborne's argument that the goal of science education is, "to help students understand a body of existing, consensually agreed and well-established old knowledge" (Osborne, 2014, p. 178) may position science as canonical knowledge. I think this is a positivist view of the nature of science, which is contrary to the contemporary view of scientific knowledge as reliable, but tentative (Lederman & Lederman, 2012).

Strategies to integrate Science and Engineering Practices in the Science curriculum.

Teacher educators should train all teachers how to teach through Inquiry-based Instruction (IBI) so that can help learners develop science and engineering practices during the science lessons. Many teachers find it hard to teach science through IBI and instead give cookbook science practical (Ssempala, 2020). The cookbook science practical just allows learners to confirm scientific principles/theories without consideration of any NOS and Indigenous knowledge.

4. Indigenous knowledge system

Indigenous knowledge refers to understandings, skills, and philosophies developed by local communities with long histories and experiences of interaction with their natural surroundings according to UNESCO's programme on Local and Indigenous Knowledge Systems (LINKS) (Hiwasaki et al., 2015). Indigenous Knowledge also referred to as traditional knowledge or traditional ecological knowledge – is a body of observations, oral and written knowledge, innovations, practices, and beliefs that promote sustainability and the responsible stewardship of cultural and natural resources (Aikenhead & Ogawa,2007).

What are the sources of indigenous knowledge?

Stories, dances, songs, and ceremonies are important sources of knowledge in Indigenous cultures. It is important to keep in mind that resources may be non-textual in nature. For example, attending a ceremony or community event could be a learning resource (Aikenhead & Ogawa, 2007).

Examples of indigenous knowledge

Archaeologists conducting excavations in Indigenous locales may uncover physical evidence of Indigenous knowledge (e.g., artefacts, landscape modifications, ritual markers, stone carvings, faunal remains), but the meaning of this evidence may not be obvious to non-Indigenous or non-local investigators (Aikenhead & Ogawa, 2007). Indigenous knowledge incorporates all aspects of life - spirituality, history, cultural practices, social interactions, language, and healing (Briggs, 2005)

Importance of indigenous knowledge

Learning from indigenous knowledge, by investigating what local communities know and have, can improve understanding of agriculture, healthcare, food security education and natural-resource management issues. (Briggs, 2005)

What are the 7 principles of indigenous?

The Seven Teachings

- Love. Love is the gift from the Eagle. ...
- Respect. Respect is the gift from the Buffalo. ...
- Courage. The Bear carries courage. ...
- Honesty. Honesty is carried by the Sabe (Sasquatch). ...
- Wisdom. The Beaver carries wisdom. ...
- Humility. The Wolf carries humility. ...
- Truth. The Turtle carries truth. (Briggs, 2005)

What is the main method of indigenous knowledge transfer?

The wisdom and practices of native communities are expressed through **stories, rituals, songs, art and hands-on, ecological practices on the land.**

What is indigenous knowledge other ways of knowing?

The intent of the phrase "Indigenous Ways of Knowing" is to help educate people about the vast variety of knowledge that exists across diverse Indigenous communities. It also signals that, as Indigenous Peoples, we don't just learn from human interaction and relationships (Briggs, 2005)

How to Incorporate Indigenous Voices into the Curriculum

1. Do your research. ...
2. Ask for local guidance. ...
3. Be culturally mindful of how Indigenous peoples are represented in the curriculum. ...
4. Teaching without appropriation. ...
5. Use Diverse Educational Materials. ...
6. Be Mindful of Terms. ...
7. Provide Alternative Learning Opportunities. (Briggs, 2005)

How can you include indigenous knowledge in a subject you teach?

Where to start?

1. Understand why incorporating Indigenous perspectives is important in science and other areas. By introducing Indigenous perspectives into your teaching your students will develop: ...
2. Involve Aboriginal people. ...
3. Use the teacher support materials. ...
4. Explore the background and research section of this website.

How does indigenous knowledge contribute to science?

Another approach is that science and Indigenous Knowledge represent two different views of the world around us: science focuses on the component parts whereas Indigenous Knowledge presents information about the world in a holistic way. With this analysis it is possible to see how one system can complement the other (Briggs, 2005)

What are some examples of indigenous knowledge systems in Uganda?

Examples include, among others knowledge about traditional medicines, traditional food, traditional hunting or fishing techniques, knowledge about animal migration patterns, and knowledge about water management.

5. CONCLUSIONS

1. Integrating the NOS in Pre-service teacher training programs will help to improve the relevance of science education in African countries
2. Integrating the Science and Engineering practices in all science curricula in Africa will help African countries train the learners with knowledge, skills, and values to solve the problems facing humanity.
3. Integration of Indigenous knowledge in science curricula at all levels of education will increase the interest of African learners in studying sciences in schools

6. RECOMMENDATIONS

To improve the relevance of science education in Africa, we should:

1. Integrate the NOS training at all levels of education (from pre-primary to tertiary level) beginning with pre-service science teachers.
2. Train the science teachers on how to teach with and about the NOS in their lessons.
3. Train science teachers on how to integrate science and engineering in their science lessons and teach science concepts through Inquiry-based Instruction.
4. Train all science teachers how to identify and integrate indigenous knowledge in all their science lessons using their context.

The researcher thinks by implementing the above-discussed strategies, we will be able to improve the relevancy of science education and train the critical human resources in the STEM field required to solve the challenges facing humanity accordingly.

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