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Representation of Nature of Science Aspects in Secondary School Physics Curricula in East African Community Countries

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Abstract. For several decades, nature of Science (NOS) has been advocated as the fourth dimension of science teaching and is a fundamental source of in-depth learning and teaching. In addition to improving learning and teaching of science, the explicit inclusion of NOS in science curricula helps the creation of a responsible citizenry. Here, we analyze the representation of NOS aspects in science curricula, particularly in the physics syllabi in four East African Community (EAC) countries: Burundi, Rwanda, Tanzania, and Uganda. These EAC countries have been purposively selected because of sharing similar culture and history as neighboring countries. To compare NOS representation in the physics content, five major topic areas (mechanics, heat and thermodynamics, oscillations and waves, electricity, and atomic physics) were randomly selected from the syllabi used in advanced level secondary schools. The paper critically analyzes the representation of NOS aspects throughout front matter (introductions and rationales) and back matter (appendices and references), content, teaching methods, and assessment procedures proposed in these physics' syllabi. Based on the analysis of data, the findings reveal that NOS aspects are not explicitly represented in the four physics syllabi analyzed. This study also found that in four syllabi reviewed, competencies were given much attention

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without any overt connection to the work of scientists. Finally, we suggest possible ways to improve NOS representation in the science curriculum.

Keywords: East African Community (EAC) countries; The Nature of Science (NOS); NOS aspects; secondary schools; science curriculum

1. Introduction

The nature of science (NOS) is considered a vital component in science education (Jenkins, 2013). Many science education reform documents around the world documented a strong correlation between scientific literacy and the understanding of the nature of science (NGSS Lead States, 2013). According to Das et al. (2019), understanding NOS is the cornerstone of informed views that can stimulate students' understanding of science. Lederman et al. (2002) emphasized that understanding the NOS assures students' abilities to assess scientific knowledge, which then acts as a driving force in engaging students in using inquiry skills (Liang et al., 2008).

A lot of efforts have been made in science education, but some challenges still exist, and they inhibit the quality of teaching and learning (Lederman, 2007; Hipkins, 2012). One of the challenges is that many science curricula give much attention to content (Cheung, 2020) rather than to the process of knowledge construction (McDonald & Abd-El-Khalick, 2017; Çetin & Kahyaoğlu, 2022). Second, a strange and persistent habit of viewing science as an irrelevant and difficult subject was reported as a strong obstacle to students learning science (Hipkins, 2012). In addition, the NOS content in the science curriculum is not yet represented in an informed manner (Vesterinen et al., 2013; Schrauth, 2009). Furthermore, lack of explicit NOS instructions, reluctance to the positive change toward NOS, and limited practical examples for easy NOS instructions in classrooms hold back science education progress (Boe et al., 2011).

Including NOS aspects in the science curriculum has been considered a practical solution to overcome the challenges mentioned above (Hipkins, 2012; Lederman, 2007; Martín-Díaz, 2006). For example, science educators view NOS as a new lens to allow a type of learning that gives much attention to both active engagement and equity among students from different backgrounds. In addition, having the NOS component in the science curriculum create a responsible citizenry capable of making rational decisions and positively impacts students to pursue a career in science (Boe et al., 2011; Lederman et al., 2013). Furthermore, it can help or guide the development of teaching and learning packages such as textbooks and other learning materials (Olson, 2018) to support the advancement of science education. It is within this regard, that science curriculum developers from some Middle East countries (Yeh et al., 2019) and those from developed countries were inspired to develop a curriculum that clearly states how NOS aspects should be integrated and taught (Taber, 2008). Some recommendations were stated for the recognition and inclusion of NOS teaching in the national curriculum of England and Wales.

Science curricula are the principal teaching resources that play a big role in giving a clear direction to the teaching and learning process (Olson, 2018). Science curricula play a key role in defining what science teachers are supposed to teach and thereby guiding learning experiences (Chiappetta et al., 2006). In this regard, the modern science curricula should not only be focused on the content and practical work, but also on social, historical, and philosophical aspects, which are referred as NOS aspects (Childs, 2015). Therefore, effective teaching and learning of NOS aspects would be easier if NOS concepts were explicitly defined in science curricula.

Explicit teaching and learning of NOS, aspects have been advocated as important issues in the science curriculum at the different levels of education (Bell et al., 2011; NRC, 2012; NGSS Lead States, 2013). For example, after the development of the NOS benchmarks, the United States of America (USA), through its National Academy of Sciences, established standards on how NOS could be integrated into the science curriculum (Taber, 2008). Likewise, New Zealand also developed six strands of the science curriculum in which four strands discuss science content while the two remaining focus on incorporating NOS to develop scientific skills and attitudes (Hipkins, 2012). However, a number of researchers still claim that there is a lack of explicitely stated NOS aspects in science curricula (Caramaschi et al., 2022). Therefore, there is a need for clarification and specification of NOS aspects in science curricula and other educational documents to break down NOS content into a simplified form to allow easy understanding among teachers and students.

Although there are little literature interventions available on NOS in African science curricula, a few African countries have tried to refine their science curricula by introducing NOS components. For example, Ogunniyi (2006) reports that the 2005 South African natural science curricula was identified as one that may help learners develop NOS understanding. However, the implicit approach was found dominating (Upahi et al., 2020).

Science curricula reforms were carried out in East African countries from around the 1960s after their independence (Mbonyiryivuze et al., 2018). Since then, science has continued to be a top school priority (Cairns, 2019), and it has been given much attention to facilitating the central goal of economic development (UNESCO, 2009). However, a few efforts to promote science in the region were put in place but could not last long due to the political instabilities, wars, destruction of infrastructures, a big loss of human capacity in the EAC (UNESCO, 2009), and the severe impact of Covid-19 on the education system (Tugirinshuti et al. 2021). In addition to this, efforts to promote NOS aspects in the science curricula in East African countries are very limited (Kinyota, 2020). This situation of very little literature and limited interventions on NOS in teaching aids materials is worrisome, particularly in East African Community countries (Kinyota & Rwimo, 2022). Referring to the vital role of NOS in improving informed views among students, Ramnarain and Chanetsa (2016) urged that the current school science curricula should be designed to help students to learn NOS. Therefore, there is a need for study on representation of NOS in the learning and teaching materials used in the region.

Purpose
The purpose of this study is to investigate the representation of NOS concepts in advanced physics syllabi from East African Community (EAC) countries. Specifically, it sought an answer to the following research question: "How are NOS aspects represented in the front matter and back matter, learning outcomes, content being taught, teaching and assessment methods in selected physics syllabi in EAC countries?"

2. Methodology

Research Approach Design
The main research approach used to get in-depth understanding of NOS representations in this paper is document analysis (Bower, 2009). This research design is used to determine the NOS aspects that have been integrated into the front matter and back matter, expected learning outcomes of students, content to be taught, and methods of teaching and assessment of analyzed syllabi. The analytical framework in this review includes eight NOS aspects that have been documented in several studies (Lederman, 2007; Lederman et al., 2002; Chaisri & Thathong, 2014).

Selection of Countries, Syllabi, and Major Topic Areas Studied
We reviewed the physics syllabi of grades 10, 11, and 12 from Burundi, Rwanda, Tanzania, and Uganda, as these countries are neighbors and share similar cultures and history. The syllabi analyzed include an advanced level physics syllabus from Rwanda (REB, 2015); three physics teacher's guides from senior four to senior six used in Burundi (Ministère de l' Education, de l' Enseignement Superieur et de la Recherche Scientifique, 2016; 2017 and Ministère de l' Education, de la Formation Technique et Professionnelle, 2018) [Ministry of Education, Higher Learning and Scientific Research, 2016; 2017 and Ministry of Education, Technical Training and Professional, 2018]; teaching syllabi for physics and mathematics, volume 2 from Uganda (NCDC, 2013); and Physics syllabus for advanced secondary Education, form V to VI from Tanzania (Ministry of Education and Vocational Training, 2017).

The authors randomly selected five major topic areas from grades 10, 11, and 12 physics syllabi. Major topic areas selected to be analyzed for their NOS representation are mechanics, heat and thermodynamics, oscillations and waves, electricity, and atomic physics. Google translate and experts in science education, particularly physicists with bilingual skills, were used to translate the French content of analysed syllabi into English.

Participants of the Study
We investigate the representation of NOS aspects in four physics syllabi that are used in East African Community countries. Three researchers/experts, participated in this study in which every researcher investigated and analyzed independently physics syllabi considered for allowing another opinions and discussion and come to consensus.

Data Analysis
Any statement that addresses process skills or competencies in the physics syllabi from EAC countries but does not make an explicit connection to the work of scientists was not considered a NOS statement. For example, engaging someone in using process skills like imagination and creativity without any connection to the scientific enterprise does not mean that he/she is knowledgeable about NOS aspects. In other words, to be counted the statements should reflect historical, philosophical, social, and psychological perspectives of science.

The NOS statement to be considered as explicitly represented had to meet the following criteria: (i) the statement should be an informed representation of NOS aspects, as described in current NOS reform documents in science education, and (ii) any statement has to be consistent throughout the whole physics syllabi in addressing the targeted NOS aspects. In other words, NOS statements were viewed throughout the whole physics syllabi in such a way that they are clearly defined in any section of the selected physics syllabi, and they were described as *"explicitly presented and coded as (+)"*. For any NOS statement to be viewed as implicitly represented in the selected physics syllabi, the following criteria were supposed to be met: (i) an informed representation of the NOS aspect could be inferred from the physics syllabi materials (e.g., statements from the front matter and back matter, content or any assessment tool that could infer the NOS representation) and (ii) for any NOS statement that possibly would be learned or taught as teachers teach normal content was taken as *"implicitly presented and coded as (×)."* Finally, any NOS aspect which does not appear either explicitly or implicitly was described as *"not represented and coded as (-)."*

3. Findings

3.1 NOS Representations in Front Matter and Back Matter of Physics Syllabi

The front matter of physics syllabi analyzed in this paper is made up of backgrounds and rationales of the syllabi, competencies, general or broad aims of science education, particularly related to teaching physics. At the same time, back matters are extended parts such as references, additional readings, and appendices of these syllabi to help the user understand–the content package of these syllabi. The analysis found that NOS concepts are not explicitly represented in the analyzed documents.

Table 1 shows that there is very little representation of NOS aspects throughout the four physics syllabi analyzed. Few concepts and statements which can implicitly support teaching NOS aspects were identified, particularly in front matters and students' learning outcomes sections, as shown in Table 1. Among eight NOS aspects that this study focused on, only six NOS aspects (tentative; observations and inferences; the relationship between theories and laws; creative and imaginations; scientific method and social and cultural embeddedness) were supposed to be taught effectively if these concepts and statements identified are explicitly linked to the work of scientists and supported throughout the physics syllabi analyzed. In addition, Table 1 also shows that no statement identified may support either explicit or implicit teaching of empirical and theory-laden aspects.

Table 1. Summary of NOS representation in the front matter, learning outcomes, and back matter of four selected physics syllabi from EAC (FM – Front Matter, LO – Student Learning Outcomes, and BM – Back Matter).

NOS aspects	Burundi			Rwanda			Tanzania			Uganda		
	FM	LO	BM	FM	LO	BM	FM	LO	BM	FM	LO	BM
Tentative	×	–	–	–	×	–	–	–	–	–	–	–
Empirical	–	–	–	–	–	–	–	–	–	–	–	–
Observations and inferences	–	×	–	–	×	–	–	–	–	–	–	–
Theory – laden	–	–	–	–	–	–	–	–	–	–	–	–
Creative and imaginations	–	×	–	–	–	–	–	–	–	–	–	–
Relationship between theories and laws	+	–	–	–	×	–	×	×	–	–	–	–
Social and cultural embeddedness	×	–	–	×	–	–	–	–	–	×	–	–
Scientific method	–	–	–	–	–	–	–	×	–	–	–	–

+: explicitly presented, –: not represented, and ×: Implicitly presented

The NOS representation through the introductions of these syllabi revealed that they mainly focused on shifting from content-based syllabi to competencies-based syllabi. They also encourage a learner-centered approach, cross-cutting issues, and advocate the removal of outdated or irrelevant content for facilitating smooth and deep learning and teaching of physics subjects (REB, 2015; MoETV, 2017; NCDC, 2013 and Ministère de l' Education, de l' Enseignement Superieur et de la Recherche Scientifique, 2017). The above description of the main purpose of the syllabi may be considered to promote the teaching and learning of NOS if mentioned content, competencies, and skills are explicitly connected to the work of scientists. Interestingly, it was not the case in the context of the four syllabi mentioned above.

Although a few statements in front matter seem to show that NOS may be learned, but still, these statements do not contain NOS concepts as described in educational reform documents, and they are also not overtly discussed in the content to be taught or in students' learning outcomes to assure smooth learning of NOS. For example, *"the ambition of the new Physics syllabus in Rwanda is to develop a knowledge-based society and hence promotes science and technology"* (REB, 2015, p. viii). In other words, this syllabus tries to link science, society, and technology together as NOS targets too. Tanzania's A-Level physics syllabus indicates that learners should focus *"on investigating natural phenomena and then applying patterns, principles, theories, and laws to explain the physical behavior of the universe"* (MoEVT, 2017, p. iii. It appears, from this statement, that teaching and learning NOS may be possible if these natural phenomena and related theories and laws are linked to the scientific enterprise. However, there is no clear trace in proposed content and student learning outcomes showing how knowledge of scientific enterprise would be integrated, so NOS was indicated as not overtly emphasized in this case.

In the physics syllabus of grade 11 from Burundi, a statement described in the preface section states that *"integration of this reform will help the student to be a change agent and a source of social and scientific development through teaching and learning activities found in the learning package that is currently in place"* (Ministère de l' Education, de l' Enseignement Superieur et de la Recherche Scientifique, 2017, p. 3). In addition to this, another statement related to NOS representation was identified in the introduction section of the grade 10 physics syllabus, where it states that *"physics is a study of the external world, how physics laws change and hence the evolution of physics"* (Ministère de l' Education, de l' Enseignement Superieur et de la Recherche Scientifique in Burundi, 2016, p.5). In other words, the above statements give an impression of NOS consideration, but it is not the case because it is not supported throughout the syllabus.

In Uganda's physics syllabus, a statement, which seems to implicitly promote NOS understanding, states that *"one of the broad aims of education in Uganda is to promote scientific, technical, cultural knowledge, skills, attitudes needed to promote development"* (NCDC, 2013, p. viii). A major problem with physics syllabi analyzed from East African Countries is that they do not specify how these statements would be connected to the work of scientists throughout different sections made up of these syllabi of physics. Analysis of the back matter of these syllabi shows that there is no appendix or additional reading which would support explicitly teaching and learning of NOS, and this confirms the low level of representation of NOS and no attention is given to NOS component in syllabi of physics in the East African Community region.

3.2 NOS Representations in the learning outcomes from A-Level Physics syllabi
In context of the East African Community countries, expected learning outcomes refer to the knowledge, skills, and aptitudes which every student should be able to demonstrate at the end of the physics curriculum.

Table 2. Students' expected learning outcomes in EAC countries

EAC country	Students learning outcomes	Observations related to the representation of NOS aspects
Burundi (Ministère de l'Education, de l'Enseignement Superieur et de la Recherche Scientifique, 2016, pp. 5–6; 2017, p. 1) [Ministry of Education,	By the end of the physics syllabus, the student should be able to: • Analyze, interpret and solve problems related to states of matter, static solids, heat, fluids, cosmology, environment, vapor and humidity, viscosity, and light. • Solve current and important problems related to electricity, electromagnetism, and mechanics (kinetics).	Curiosity, imagination, and creativity with an open mind seem to be linked to a NOS aspect, but it is not explicitly described how this aspect should be linked to the scientific enterprise while viewing the whole physics syllabi.

Higher Learning, and Scientific Research, 2016, pp. 5–6; 2017, p. 1] (Ministère de l'Education, de la Formation Technique et Professionnelle, 2018, p. 3) [Ministry of Education, Technical training, and Professional, 2018, p. 3]	• Solve current and important problems related to periodic phenomena, alternative current, fluids mechanics, atomic physics, and electronics Candidates should also be able to develop the following attitudes and competencies: • Observation and communication skills • Curiosity, imagination, and creativity skills with an open mind • Accuracy and precision • Critical thinking skills • Self-respect and respect views of others • Interest in scientific and technical development to serve society • Awareness of food security laws • Environmental awareness • A citizen who can continue further studies • Relationship between physics and other scientific disciplines	
Rwanda (REB, 2015, pp. xix–xxi)	**Knowledge and understanding** Candidates should be able to demonstrate knowledge and understanding of: • Scientific phenomena, facts, laws, definitions, concepts, and theories. • Scientific vocabulary, terminology, and conventions (including symbols, quantities, and units). • Scientific instruments and apparatus used in Physics, including techniques of operation and aspects of safety. • Scientific quantities and their determination. • Scientific and technological applications, with their social, economic, and environmental implications. **Handling information and solving problems** Candidates should be able to handle information and solve problems, using written, symbolic, graphical, and numerical forms of presentation to: • Locate, select, organize and present information from a variety of sources. • Translate information from one form to another. • Manipulate numerical and other data. • Use the information to identify patterns, report trends, and draw conclusions.	Some concepts of NOS, such as scientific facts, laws, scientific processes, pattern recognition, observation, interpretation of data, prediction, etc., are weakly represented in learning outcomes, and the link between science and society is very weakly shown. Moreover, these are not coherently presented, and their link with the scientific enterprise is not explicitly made. So, there is a weak representation of NOS aspects.

	• Give reasoned explanations for phenomena, patterns, and relationships. • Make predictions and hypotheses. • Apply knowledge, including principles, to new situations. • Demonstrate an awareness of the limitations of physics theories and models. • Solve problems. **Experimental skills and investigations** Candidates should be able to: • Observe, give feedback, and plan experiments and investigations. • Collect, record, and present observations, measurements and estimates. • Analyze and interpret data to reach conclusions. • Evaluate methods and quality of data and suggest possible improvements. • Use ICT in solving problems.	
Tanzania (Ministry of Education and Vocational Training, 2017, p. v)	By the end of the physics syllabus, the student should be able to: • Understand the language of Physics. • Explain theories, laws, and principles of Physics. • Understand the scientific method in solving problems. • Promote scientific and technological knowledge and skills in management, conservation, and sustainable use of the environment. • Promote manipulative skills to manage various technological appliances. • Promote self-study for self-advancement in new frontiers of Physics. • Appreciate the role of ICT in the process of learning Physics.	Few concepts of NOS, such as scientific theories and laws are mentioned. A scientific method has been identified, but it is not supported throughout the physics syllabus. In other words, it is not linked to the work of scientists.
Uganda (NCDC, 2013, p. 6)	At the end of the Physics syllabus, the learners should be able to: • Recognize problems that can be dealt with using methods, concepts, principles, models, and theories of physics • Recognize the use of and manipulation of the apparatus and equipment common in a physics laboratory • Design and carry out practical investigations and experiments,	A few concepts of NOS, such as scientific theories, models, scientific processes, investigation, and experimentation, are very poorly represented in learning outcomes, the link between science and society is not shown. Moreover, their link with the scientific enterprise is not made. So, there is a

	describe and explain the procedures used as well as their effectiveness and limitations • Handle all practical work with the accuracy required to obtain the desired results • Define terms related to various concepts in physics and explain their relationship to materials and phenomena in the environment. • Discuss the use and effectiveness of theories or models in explaining physical phenomena as well as events in the laboratory and the environment.	very poor representation of NOS aspects.

Table 2 shows that the NOS component in learning is represented very poorly. For example, referring to NOS dimensions recommended to be in the science curriculum (Lederman et al., 2002) and expected learning outcomes (REB, 2015; NCDC, 2013 and MoEVT, 2017, it is very clear that NOS is not formally and explicitly recognized in these syllabi. In other words, these expected learning outcomes mainly focus on understanding the content and practical work. In addition, it is also not easy to see clearly in any of the above-mentioned learning outcomes how a student may be helped to develop skills related to scientific knowledge construction.

3.3 NOS Representations in Content to be taught to students
We randomly selected five topic areas from grades 10, 11, and 12 physics syllabi of all countries that have been considered in this paper. Major topic areas to be analyzed for their NOS representation are mechanics; heat and thermodynamics, oscillations and waves; electricity; and atomic physics. The analysis of the content throughout these four physics syllabi shows that there is very little representation of NOS aspects in almost all units discussed in those curricula (Tables 3 to 7).

We found that all physics students of grade 11 from Rwanda, Uganda, and Tanzania and physics students of grade 12 from Burundi are supposed to study 'waves.' For example, in Rwanda, the term wave is under a unit called "oscillations and waves," in Uganda, it is under a unit named 'Waves' while in Tanzania, the term "wave" is under a unit called 'vibrations and waves' as shown in Table 5 below. In Burundi, the term "wave" is described only in grade 12 under two units named: "interferences and stationary waves" and "sound waves." The topic of heat and thermodynamics is discussed to grade 10 students from Rwanda and Burundi, while the same topic is taught to grade 11 and 12 students from Tanzania and Uganda, respectively as shown in Table 4.

Projectile motion is under mechanics, and is taught to all students of grade 10 from Rwanda and grade 11 from Tanzania, Burundi, and Uganda (Table 3). The topic on electricity is taught to grades 10 and 11 students from Rwanda, grade 12 from Tanzania and Uganda, and grade 11 from Burundi (Table 6). Atomic physics is taught to students of grade 11 from Rwanda and all students of grade 12 from Tanzania, Burundi, and Uganda (Table 7).

Differences were noted during the selection of the topics included in this paper. First of all, it was noted that there is a difference in students' levels. For example, in Rwanda and Burundi, the advanced level of secondary school is from grade 10 to 12, while in Uganda and Tanzania, students are in the advanced level of secondary school from grade 11 to grade 12. Second, it was identified that some topics were taught from grade 10 up to grade 12 in some countries but not all in other countries. For example, the topic of astrophysics and environmental physics is taught to advanced-level students in Rwanda, Burundi, and Tanzania but not taught to the same level students in Uganda.

Table 3. Selected content of projectile motion to be taught to A-level students from EAC

EAC Countries	**Topic areas**	**Unit to be taught**	**Unit objectives**	**Content**	**Observations related to the representation of NOS aspects**
Burundi (Ministère de l'Education, de l'Enseignement Superieur et de la Recherche Scientifique, 2017, pp. 215–216) [Ministry of Education, Higher Learning, and Scientific Research, 2017, pp. 215–216]	Mechanics	Projectile motion	• study the composition of two uniform rectilinear movements • demonstrate that the range of the flight results from the composition of two movements • calculate the horizontal shot range	• composition of two uniform rectilinear movements • Derivation of projectile motion parameters	None of the NOS statements was identified.

Rwanda (REB, 2015, pp. 14–15)		Projectile motion	• Define and explain terms used in projectile • Relate projectile motion to linear. • Appreciate applications of projectile • Resolve projectile motion in horizontally and vertically components. • Derive equations of projectile motion. • Determine the maximum height and horizontal range in projectile motion	• Definition of projectile motion and related terms. • Applications of projectile motion. • Graphs of projectile motion. • Expressions of projectile motion (horizontal range and maximum height).	None of the NOS aspects identified.
Tanzania (Ministry of Education and Vocational Training, 2017, p. 6)		Projectile motion	• Describe projectile motion parameters • Derive projectile motion parameters • Describe the applications of projectile motion	• Projectile motion parameters • Derivation of projectile motion parameters • Applications of projectile motion	None of the NOS statements identified.
Uganda (NCDC, 2013, p. 28)		Projectile motion	• Define flight and range. • Calculate time for flight, maximum height, and range. • Describe the applications of profile motion.	• Projectiles (projectile motion on an inclined plane is beyond the scope) • Time of flight, maximum height, and range (range along a horizontal plane only) • Applications of projectile motion	None of the NOS statements identified.

It would be vital if students were helped to learn the history of mechanics from Aristotle to Newton's period and understand why some of the scientific explanations given by different physicists were refuted. For example, it would be better to discuss how projectile motion posed a problem to the second type of motion proposed by Aristotle, which is known as the "violent motion" of a body and was defined as a compulsory motion caused by an external influence (Rovelli, 2015). In addition, it was not easier to understand why a projectile continues to move while it is separated from its launcher (Barahona et al., 2014). Contrary to this, the unit objectives and content of projectile motion proposed by curriculum developers in physics syllabi from EAC encourage memorization of the content. For example, the verbs like define, calculate and derive, most of the time, help students cram how different mechanical concepts would be derived rather than linking these concepts to the work of knowledge construction, which in the end may help learners interpret or understand natural phenomena in mechanics in a better way.

Table 4. Selected content of heat and thermodynamics to be taught to A-level students from EAC

EAC Countries	Topic areas	Unit to be taught	Unit objectives	Content	Observations related to the representation of NOS aspects
Burundi (Ministère de l'Education, de l'Enseignement Superieur et de la Recherche Scientifique, 2016, pp. 167–168) [Ministry of Education, Higher Learning, and Scientific Research, 2016, pp. 167–168]	Heat and Thermodynamics	State of matter and Calorimetry	• Interpret different temperature scales • Distinguish different states of matter • Differentiate different phenomena in changes in states of matter • Explain the expansion in solids, liquids and gases.	• Temperatures scales • Specific heat capacity • States of matter • Changes in states of matter • Expansion of solids, liquids and gases	Temperature scales might be used to teach NOS, however, it is not explicitly mentioned in this content.
Rwanda (REB, 2015, pp. 19 – 20)		Applications of thermodynamics laws	• Differentiate the internal energy and total energy • Explain the work done • The state first, second laws of thermodynamics and their applications • Solve problems related to Carnot	• Internal energy and total energy • Work done by expanding gas • First and second laws of thermodynamics	None of the NOS aspects identified.

			cycle, Carnot engine, diesel engine, refrigerators,	• The applications of the first and second laws of thermodynamics • The efficiency of the heat engine • Heat engine and climate change	
Tanzania (Ministry of Education and Vocational Training, 2017, pp 18 – 22)		Heat	• Describe the thermometric properties of a substance and scale of temperature • Explain ways of thermal heat transfer • Explain thermodynamics processes • Identify specific heat capacity of gases • Establish the first law of thermodynamics and its applications	• Thermometers • Heat transfer • The first law of thermodynamics	None of the NOS statements was identified.
Uganda (NCDC, 2013, pp 73 – 74)		Thermodynamics	• Definer internal energy of an ideal gas • Derive the work done • Explain thermodynamics processes • Define principal specific heat capacities C_p and C_v of an ideal gas • Define the first law of thermodynamics and its applications	• Internal energy • Work done by expanding ideal gas • Thermometric processes • Principal specific capacities • The first law of thermodynamics and its applications	None of NOS statements identified.

Looking at the proposed content in Table 4, it is very clear that this content may not help students to develop a philosophical background in thermodynamics. In addition, it has been identified that NOS concepts are not explicitly included. Although the topic does not define how content is linked to the work of scientists, such as the historical development of concepts of heat, calorific properties, as well as thermometers, temperature scales, such linking could be very useful in NOS teaching.

Table 5. Content of waves to be taught to grades 11 and 12 students from EAC

EAC Countries	Topic areas	Unit to be taught	Unit objectives	Content	Observations related to the representation of NOS aspects
Burundi (Ministère de l'Education, de la Formation Technique et Professionnelle, 2018, pp. 136 - 173) [Ministry of Education, Technical Training, and Professional , 2018, pp. 136–173]	Oscillations and waves	Interferences and stationary waves	• Define and interpret the interference phenomenon • Distinguish constrictive and destructive interferences • Apply interference phenomenon • Define stationary wave • Interpret phenomena of stationary waves • Identify different stationary waves	• Interference phenomena • Constructive and destructive interferences • Application of the interference • Stationary wave • Different stationary wave phenomena	None of the NOS statements identified.
		Sound waves	• Define sound wave • Determine the longitudinal nature of sound wave • Identify characteristics of a sound • Identify properties of sound waves	• Sound wave • Nature of sound wave • Characteristics of a sound • Properties of sound waves	
Rwanda (REB, 2015, p. 28)		Propagation of mechanical waves	• Explain the wave concept. • Explain the terms amplitude, frequency, displacement, wavelength, and wave phase. • Explain the terms transverse and longitudinal waves.	• Wave concept. • Types of waves. • Waves Terms. • Characteristics of waves. • Relationship between wavelength, frequency	None of the NOS statements identified.

			• Explain the terms progressive and stationary waves. • Explain the phase of vibration. • Explain reflection, refraction, diffraction and interference of waves. • Explain Young double-slit experiment.	(Period), and velocity. • Properties of waves (Reflection, refraction, interference, diffraction). • Young double-slit experiment. • Progressive and stationary waves. • Equation of a progressive wave. • Example of progressive wave on a vibrating string.	
Tanzania Tanzania (Ministry of Education and Vocational Training, 2017, p. 23)	Vibrations and waves	Waves	• Distinguish progressive and stationary waves • Deduce the expressions for progressive waves and stationary waves • Deduce the principle of superposition of waves	• Progressive and stationary waves • Expressions for progressive and stationary waves • Principle of superposition	None of the NOS statements identified.
Uganda (NCDC, 2013, p. 50)	Waves	Waves	• Relate the different wave properties and use them to explain the different wave behaviors • Explain the formations of stationary waves • Explain the occurrences of resonance, beats, Doppler Effect and polarization.	• Concept of wave • The terminology used in waves • Relationships between frequency, period, wavelength velocity • Transverse and longitudinal waves	None of the NOS statements identified.

As shown in Table 5, none of the NOS aspect was represented in content of waves in physics syllabi. It would be better if the developers of these syllabi added content elements related to history, sociology, and philosophy of science. For example, if students were exposed to historical aspects of waves, their social aspects, and empirical evidence leading to the evolution of the concepts of the waves, this could help them understand the philosophical view behind it and its application in daily life. In addition to this, the content presented under the wave unit encourages memorization of wave concepts rather than understanding the reason for learning these concepts. Therefore, the content provided in Table 5 is evidence of low representation of NOS.

Table 6. Selected content of electricity to be taught to A-level students from EAC

EAC Countries	Topic areas	Unit to be taught	Unit objectives	Content	Observations related to the representation of NOS aspects
Burundi (Ministère de l' Education, de l' Enseignement superieur et de la Recherché Scientifique, 2017, p. 28) [Ministry of Education, Higher Learning, and Scientific Research, 2017, p. 28]	Electricity	Nature of current electricity	• Identify factors of The conduction of electricity in metals • Interpret the mechanism of electric conduction in metals, electrolytes, and gases • Define a generator • Determine the quantity of electricity • Define and measure the current intensity • Define and use a unit of quantity of electricity	• Factors influence conduction of electricity in metals • Mechanism of electric conduction • A generator • Quantity of electricity • Unit of current intensity	None of the NOS statements identified.
Rwanda (REB, 2015, p. 10)		Kirchhoff's laws and electric circuits	• Recall sources of electric current, EMF electric, and receptors/appliance. • Describe components of a simple electric circuit. • State Kirchhoff's laws	• Review elements of a simple electric circuit and state the application. • Definition of electromotive force. • The voltage or terminal potential and electromotive force	None of the NOS statements identified.

			• Explain the difference between potential difference and electromotive force. • Apply Kirchhoff's laws to problems in electric circuits. • Acquire practical skills	• Sources of electric current and electric receptors/appliances. • Internal and external resistance, the potential difference across a cell. • Connection of electrical current source and resistors either in series or parallel or mix-up. • Kirchhoff's laws (loop rule and junction rule). • Application of Kirchhoff's laws to simple circuits.	
Tanzania (Ministry of Education and Vocational Training, 2017, pp. 37–38)		Electric conduction in metals and gases	• Describe the mechanism of electric conduction in metals • Determine the resistivity of a conductor • Investigate the temperature coefficient of resistance • Analyze electrical networks • Investigate the conduction of electricity in gases • Explore optical spectra for gases • Identify the applications of conduction of electricity in gases	• Mechanism of electric conduction in gases • The resistivity of a conductor • Temperature coefficient of resistance • Electrical networks • Optical spectra for gases • The applications of conduction of electricity in gases	None of the NOS statements identified.
Uganda		Current electricity	• Define the coulomb	• The coulomb • Charge	None of the NOS statements identified.

(NCDC, 2013, p. 85)			• Define electric current • Explain the concept and significance of the potential difference • Define volt, emf, resistance, and ohm • State and verify ohm's law • State Kirchhoff's laws of electricity • Solve circuits problems using Kirchhoff's laws	• Potential difference • Significance of potential difference • The volt • emf • Resistance • The ohm • Verification of ohm's law • Kirchhoff's laws • Circuits problems using Kirchhoff's laws	

Table 6 provides another piece of evidence of the very low representation of NOS aspects in EAC physics syllabi. Both experimental observations and theories can be used to integrate the historical perspective of electricity and its evolution or develop imagination and creativity through building-model of electrical circuits and electric concepts and phenomena. Contrary, unit objectives and content under electricity from East African countries' physics syllabi lack explicit connection to the scientists' work or the scientific enterprise. In addition to this, its content does not provide direction on how NOS aspects are shown in educational reform documents.

Teaching and learning electricity should always help students understand macroscopic level observations from microscopic level theories, which is the solid foundation of scientific reasoning skills and the current initiatives in technology. This may help them interpret complex ideas of electrical phenomena and models for understanding electromagnetic phenomena rather than defining, deriving, and calculating concepts in electricity. It may be a good stimulus to learn the evolution of electricity theories, which in the end lead to the advancement of the study of electricity. For example, "electric effluvia" was refuted due to its inability to give scientific explanations of electric repulsion or electric transmission (Barahona et al., 2014).

Table 7. Selected content of atomic physics to be taught to A-level students from EAC

EAC Countries	Topic areas	Unit to be taught	Unit objectives	Content	Observations related to the representation of NOS aspects
Burundi (Ministère de l' Education, de la Formation Technique et Professionnelle, 2018, p. 307) [Ministry of Education, Technical Training, and Professional 2018, p. 307]	Atomic Physics	Introduction to atomic physics	• Define the objective and importance of atomic physics • Distinguish the physics of an atom from physics with atoms • Identify applications of atomic physics • Get knowledge about the dimensions of the atomic nucleus and the constituents of matter	• The objective of atomic physics • Physics of an atom and physics with atoms • Applications of atomic physics • Atomic nucleus Constituents of matter	None of the NOS statements identified.
Rwanda (REB, 2015, p. 36)		Atomic models	• Recall the duality nature of light. • Explain the structure of the atom. • Explain atomic radiation spectra. • Explain evidence of energy levels in an atom.	• Structure of an atom. • Atomic models (Rutherford's atomic model and Bohr's atomic model) • Energy levels and spectral lines.	Explanation of evidence of energy levels in an atom, and Rutherford and Bohr's models may be used to teach some of the aspects of NOS. However, it is not mentioned explicitly. So, there is no or utmost very weak representation of NOS aspects.
Tanzania (Ministry of Education and Vocational Training, 2017, p. 46)		Structure of an atom	• Describe the Rutherford and Bohr models of an atom • Analyze atomic energy levels	• Rutherford and Bohr models of an atom • Atomic energy levels	Rutherford and Bohr's models may be used to teach some of the aspects of NOS. However, it is not mentioned explicitly. So, there is no or utmost very weak representation of NOS aspects.
Uganda (NCDC, 2013, p. 102)		Charged particles	• Describe the discharge tube phenomena as pressure is reduced • Describe the production of cathode rays and positive rays	• Discharge tube phenomena • Production and properties of cathode rays • Production and	None of NOS the statements identified.

			• State the properties of cathode rays and positive rays • Define specific charge	properties of positive cathode rays • Cathode rays and ion beams in electric and magnetic fields • Specific charge	

Even though most units' objectives in Table 7 focus on memorizing concepts about the atom, two unit objectives under atomic physics were identified as the ones which might help in developing NOS knowledge among students either implicitly or explicitly taught. For example, the following unit objective: *"explain evidence of energy levels in the atom"* was identified in grade 12 physics syllabus from Rwanda and may help in the teaching of NOS aspects, such as tentativeness, empirical, and the role of observations and inferences in developing theories related to energy levels. Another unit objective which is "*Rutherford and Bohr's models"* was also identified in physics syllabi of Rwanda and Tanzania and this statement may support development of creativity and imagination aspect. Table 8 shows that targeted NOS aspects in the study are almost not represented in the five topic areas selected from all four physics syllabi considered. Contrary to other topic areas selected in this study, atomic physics has been identified as an only topic that contains few statements which might help teachers teach tentative and empirical aspects implicitly, as shown in Table 8 below.

Table 8. Summary of NOS representation in the selected topic areas from physics syllabi from EAC countries (Topic 1: Mechanics, Topic 2: Heat and thermodynamics, Topic 3: Oscillations and waves, Topic 4: Electricity, and Topic 5: Atomic physics).

NOS aspects	Burundi					Rwanda					Tanzania					Uganda				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Tentative	–	–	–	–	×	–	–	–	×	–	–	–	–	×	–	–	–	–	–	–
Empirical	–	–	–	–	×	–	–	–	×	–	–	–	–	–	–	–	–	–	–	–
Observations and inferences	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Theory – laden	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Creative and imaginations	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Relationship between theories and laws	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Social and cultural embeddedness	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Scientific method	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

+: explicitly presented, –: not represented, and ×: Implicitly presented

3.4 NOS representations through teaching and assessment methods

Teaching and assessment methods are important in defining what relevant skills or knowledge a student may demonstrate and how. It is the role of curriculum developers to propose how intended concepts might be taught and assessed. Since, the teaching of NOS aspects combines psychology, history, sociology, and philosophy of science (McDonald & Abd-El-Khalick, 2017) as important skills a student needs to demonstrate, it is mandatory for any teaching package such as curricula or syllabi to describe how these NOS aspects would be taught and assessed. Contrary to it, the present syllabi in EAC do not explicitly specify how these important aspects should be taught and assessed. All four physics syllabi analyzed, proposed teaching methods that would help learner-centered pedagogy as the best way of promoting competencies and skills. But these teaching methods lack explicit and reflective-based pedagogy to explicitly improve students' knowledge about the nature of science. Assessment methods discussed in these syllabi respond to the knowledge or content assessment rather than reasoning skills that may improve students' understanding of the nature of science.

4. Discussions of the findings

The analysis of the four A-level physics syllabi indicates that the topics or units to be taught are good in respect of inclusion of NOS aspects. For example, topics such as atomic physics, astrophysics, environmental physics, mechanics, oscillations, and waves are good topics to teach NOS. If these topics are well linked to the works of scientists or scientific enterprise, it will help students acquire skills related to scientific knowledge construction.

In general, we found that there is a lack of NOS representation in both front matter and back matter and learning outcomes. The critical issue of low representation of NOS aspects in these syllabi comes out while looking in detail throughout unit objectives and content. In other words, it is not clearly defined how students may gain skills related to knowledge construction or how scientific enterprise operates. The representation of targeted NOS aspects is missing or poorly presented in the content of five topic areas selected from all four physics syllabi considered. Unlike other topic areas selected in this study, atomic physics has been identified as the only topic which contains a few statements which might help in teaching tentative and empirical aspects implicitly. The syllabi in EAC do not explicitly specify how these important NOS aspects should be taught and assessed. The results agree with that of Kinyota (2020), who urged that the NOS was not given much attention in Tanzania's science curriculum, where the term "nature of science" was not identified throughout the whole curriculum analyzed. The findings are also consistent with the results with Arumit and Akerson (2022) where NOS aspects were reported as ~~a~~ negligible content in Turkey middle schools' science curriculum.

According to Lederman and Lederman (2014), the teaching of NOS aspects would be helpful for deeper understanding of science rather than rote memorization. In addition to this, it is very important to have physics syllabi that would help students develop new ideas freely, innovate new solutions, free science from rigid rules, and attract attention and curiosity among students and teachers to be engaged in the scientific enterprise (Al-Abdali & Al-Balushi, 2016). Therefore, it would be better if the proposed content under the atomic physics unit could support the teaching of aspects of NOS and hence promote a deep understanding of science.

Insufficient representation of NOS aspects in the teaching resources is not only an issue of this study, but it is widely known (Chaisri & Thathong, 2014; Yeh et al., 2019). For example, in a study by Taber (2008), it was identified that the national curriculum of England lacked a more explicit model to teach NOS aspects. Ferreria and Morais (2013) reported that science construction knowledge was mostly absent in the Portuguese science curriculum. In addition, a study of analysis of Turkey' science curriculum reveals that there is not only a low representation of NOS aspects, but also a connection between the curriculum and textbooks is inadequate to support NOS teaching in the classroom (Izci, 2017). Similar results were reported in the study of Caramaschi et al. (2022), where the aspects of NOS in the Italian advanced secondary school curriculum are not explicitly represented. A recent study on representations of NOS in the science curriculum in Norway showed that social values and scientific practices are emphasized in the curriculum (Mork et al., 2022), which contrasts with other related studies. NOS aspects have also been included explicitly in the science curriculum in China, however, the majority of the NOS aspects are represented implicitly in five textbooks analyzed and the 'scientific method' is inconsistently or poorly represented in three of the five books (Zhuang et al., 2021).

Furthermore, Olson (2018) revealed that NOS aspects rarely occurred from standards documents of nine diverse countries (Australia, Canada, Colombia, Indonesia, Lebanon, Mexico, Thailand, South Africa, and the USA), with the notable exception of Australia. And these standard documents do not clearly define pedagogical support to break down NOS content into meaningful experiences for the students. Even though little attention to NOS representation in science curricula is known worldwide, this study shows that the situation is very scary and worrying in EAC countries.

5. Conclusions and Recommendations

This study reveals that, in general, NOS concepts are not explicitly represented in all statements from front matter and back matter (Table 1), learning outcomes (Table 2), and physics content (Tables 3 to 7) based on the analysis of four physics syllabi of EAC. The findings reveal that four reviewed physics syllabi mainly focus on shifting from content-based syllabi to competencies-based syllabi. In these syllabi, competencies were given much attention without an overt connection to the work of scientists. In other words, having a science curriculum that addresses curricular competencies, practical work skills, and good content does not necessarily mean integrating NOS. Proposed teaching and assessment methods in physics syllabi analyzed mainly focus on promoting competences and memorizing content rather than understanding the process of the scientific enterprise.

This paper also identified that the physics syllabus from Burundi contains few NOS statements from its front matter compared to physics syllabi from Rwanda, Tanzania, and Uganda. In addition, even though these few NOS statements might promote the teaching of NOS concepts, particularly in the physics syllabus from Burundi, these statements were not supported through learning outcomes, content, teaching, and assessment methods. Among five major topic areas considered, the atomic physics topic was identified as an area that may support implicit teaching of NOS aspects in EAC countries. Furthermore, tentative and empirical aspects were implicitly presented in the topics of atomic physics and electricity in physics syllabi in Rwanda, Burundi, and Tanzania. Other remaining targeted NOS aspects were identified as neither implicitly nor explicitly presented in all physics syllabi from the EAC countries. We found that both teaching and assessment methods do not explain how NOS concepts might be taught or assessed.

A low representation of NOS aspects and a notable decline of NOS aspects in many standards documents (Lederman & Lederman, 2014; Olson, 2018), is an indicator of losing an important stimulus that is an insight for learning science. It is now time for science educators to raise their voices to save this important aspect of science. Therefore, the recommendation to the curriculum developers from East African countries is to revisit current advanced physics syllabi by integrating NOS concepts in an explicit manner. In addition, there is an urgent need for other related learning materials, such as physics textbooks which might awaken physics teachers to consider NOS components while integrating NOS concepts and to guide students for easy learning of NOS aspects without much support from their teachers.

Furthermore, due to little available literature related to NOS education in general in the region, we recommend that scientists and researchers from the East African countries study NOS representations in the different learning materials used in the region for good interventions which can overtly link the described contents from advanced level physics syllabi to the work of scientists or the development of knowledge construction.

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