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The status of and challenges facing secondary science teaching in Tanzania: a focus on inquiry-based science teaching and the nature of science

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ABSTRACT

Although Inquiry-Based Science Teaching (IBST) and the Nature of Science (NOS) are well documented as important aspects of teaching science subjects in schools, little research has been undertaken to understand how these aspects feature in secondary school science curricula in Tanzania. Thus, this study examined the extent to which IBST and NOS are featured in secondary school curriculum documents for science subjects. In addition, the challenges facing the integration of IBST and NOS in science teaching in Tanzanian secondary schools are highlighted. By analysing five curriculum documents and the Basic Education Statistics in Tanzania, the study established that IBST and NOS are neither formally recognised as important aspects of science education, nor given due attention in curriculum documents. Moreover, a lack of coherence among various elements of the curriculum, which can affect the integration of IBST and NOS, was observed. Finally, it was established that several challenges such as larger class sizes, insufficient time allocation and overemphasis on content coverage need to be addressed so that IBST and NOS could be fully integrated into science teaching in Tanzania. The study does not only highlight the theoretical trends related to IBST and NOS, but also discusses their theoretical and practical implications for science teaching.

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Curriculum; inquiry-based learning; nature of science; Tanzania

Introduction

The role of Science, Technology, Engineering and Mathematics (STEM) education in realising social and economic development is well acknowledged (Fitzgerald et al., 2019; Semali & Mehta, 2012). Thus, improving the teaching of STEM subjects has become a top school priority (Cairns, 2019). In relation to this, IBST (Areepattamannil, 2012; Cairns & Areepattamannil, 2019; Fitzgerald et al., 2019; National Research Council (NRC), 1996) and informed views of NOS (Billingsley & Fraser, 2018; Das et al., 2019; Fernandes et al., 2018; Herman et al., 2015) are among the essential aspects of science teaching and scientific literacy in general. Not only are the two aspects related, but also science educators hope to achieve one through the other. For instance, there are assumptions that

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students can achieve informed views of NOS when they are exposed to learning through IBST (Das et al., 2019; Lederman et al., 2002; Liang et al., 2008). Thus, using the two aspects together can provide a better framework for understanding the status of science education in Tanzania and the challenges affecting it. To demonstrate further, according to Cairns and Areepattamannil (2019) and Nadelson et al. (2013), IBST calls for science teaching and/or learning to be done in a way almost similar to the actual science practice done by professional scientists. Although research on the effects of IBST on science achievement has produced mixed results (Cairns, 2019), IBST is associated with enhanced students' interests and self-efficacy of science (Cairns & Areepattamannil, 2019; Fitzgerald et al., 2019), conceptual understanding of science (Gaskill et al., 2006; Linn et al., 2003) and the development of self-regulation skills (Crujeiras-Pérez & Jiménez-Aleixandre, 2019; Moote, 2019). Understanding NOS ensures that science teaching and learning is informed through the assumptions about the nature of scientific knowledge. In that sense, as an epistemology of science, NOS is related to 'understanding how scientific knowledge is developed, appreciating the characteristics of that knowledge and being aware of the values inherent to the discipline' (Burke et al., 2018, p. 1152). Also, informed views of NOS have been associated with students' understanding of science (Das et al., 2019; Liang et al., 2008), students' abilities to evaluate science knowledge (Lederman et al., 2002; Liang et al., 2008) and motivation to engage in scientific investigations (Liang et al., 2008).

As it is in other countries, curriculum documents in Tanzania recognise the role of scientific literacy on economic and industrial development (MoEVT, 2005, 2007, 2009a, 2009b, 2009c). It is therefore not surprising that the documents advocate for some aspects (e.g. class level objectives) of IBST, and NOS such as planning and conducting science investigations and understanding the nature of science (MoEVT, 2005, 2007, 2009a, 2009b, 2009c). Unfortunately, IBST and NOS represent under-researched areas in Tanzania. Only a few studies (e.g. Mkimbili et al., 2017) have focused on this subject in Tanzania. Specifically, Mkimbili et al. (2017) investigated the extent to which science teachers practice IBST. They found that teachers rarely incorporate IBST in their teaching due to challenges such as resource constraints and overemphasis on high stakes testing. Although curriculum documents encourage teachers to use student-centred pedagogy (MoEVT, 2009a, 2009c), teachers in Tanzania prefer to use teacher-centred pedagogy (Kafyulilo & Tilya, 2019; Kinyota & Kavenuke, 2018; Kitta & Tilya, 2010). This might be due to the disjunction among curriculum elements. Meanwhile, the lack of alignment or coherence among various curriculum elements (e.g. goals, teaching activities, assessment and content) has been associated with difficulty in implementing educational reforms (Mhlolo & Venkat, 2009; Sullanmaa et al., 2019). Thus, it is very important to investigate whether the integration of IBST and NOS is supported at various levels of curricula. So far, no study has associated teachers' preference of teacher-centred pedagogy with curriculum coherence in Tanzania. Therefore, this paper focuses on two dominant frameworks that are related to how school science should be conducted – (IBST) and (NOS). By gauging science curricula in Tanzania at the intended, and implemented levels against these frameworks, this paper intends to shed light on the current status of science teaching in Tanzania as well as the challenges experienced. To accomplish its objectives, the paper addresses two questions; first, to what extent are IBST and NOS promoted in secondary school science curriculum documents in Tanzania? Second, what challenges are likely to face the integration of IBST and NOS in science teaching in Tanzania?

Education and science education in Tanzania: historical and curriculum contexts

After gaining independence from the British in 1961, Tanzania (then called Tanganyika) made efforts to transform her educational system. In particular, the country hoped to make major transformations that would lead to liberation from colonial education (Nyerere, 1968). For instance, the University of Dar es Salaam (formally University College, Dar es Salaam), established in 1961, was tasked with preparing post-independent intellectuals who would lead the liberation struggles. The Education for Self-Reliance (ESR) (Nyerere, 1968), which aimed at preparing a socialist society, introduced new educational reforms including the use of Swahili as a language of instruction in basic education and making education more practical through an integration of vocational training. Nonetheless, due to intensified globalisation and the introduction of Structural Adjustment Programs (SAPs) in the 1980s, other education reforms that aimed at preparing citizens who could compete in the global science-and–technology-driven world took place (Ministry of Education, Science and Technology [MoEST], 2019). These reforms, one can say, marked an important shift from socialism to capitalism. Thus, the 1995 Education and Training Policy named science and technology as a strategic aspect of education (MoEST, 2019). Since then, science education has been considered as an important aspect of formal education in Tanzania (Kafyulilo & Tilya, 2019). That is to say, science is an important component of school curriculum from early grades to university level. In primary schools (standard 1–7), students learn science through an integrated curriculum, in which science concepts, theories and laws are taught as a single subject called science and technology. However, at secondary education level (Form 1-6), which is the focus of this paper, the curriculum adopts a subject-based model, whereby each science subject – physics, chemistry and biology – is taught separately. Teaching and learning are guided by a curriculum document called 'syllabus' (MoEVT, 2009c, p. i). The syllabus stipulates the goals of education in Tanzania in general, the goals of education at secondary school level and the goals of each specific subject. Given that Tanzania implements a centralised education system, the subject-specific goals outline what students should be able to know and practice by the end of each grade, across the whole country. These subject-specific goals are equivalent to the national learning standards in countries such as the U.S.A. In addition, the syllabi outline all topics and suggest the relevant teaching strategies, assessment activities and teaching/learning resources for each topic (and sub-topics). In terms of assessment, secondary school students must sit for three nationally and centrally administered examinations (Kafyulilo & Tilya, 2019). All the examinations – one at Form Two level (grade 9), another at Form Four level (grade 11), and another at the end of high school – are used to make important decisions such as placement of students in the higher levels of education, and employment. Generally, in Tanzania, students perform poorly in science and mathematics as compared to social science subjects (MoEST, 2019). As a consequence, the proportion of students majoring in science subjects in Form Three, and Form Five (when students are to make subject choices) tend to be lower compared to those who choose social science subjects (Kinyota & Kavenuke, 2018), leading to a vicious circle of scarcity of science and mathematics teachers in Tanzania (Kafyulilo & Tilya, 2019).

In summary, the education system in Tanzania follows a 2-7-4-2-3/4/5 model, which corresponds to two years of pre-primary, 7 years of primary, four years of lower secondary, two years of advanced secondary (high school) and three/four/five years of university education. Moreover, there are non-formal education programmes such as vocational training (at vocational colleges). On the one hand, for public schools, Swahili is used as a Language of Instruction (LoI) from pre-primary to primary school while English is taught as a subject at this level. On the other hand, English is used as LoI from secondary to university level. Enrolment for pre-primary, primary and secondary basic education (2-7-4) is free and compulsory for all children at the age of 4/5, 6/7 and 13/14 respectively. As per the 2-7-4-2-3/4/5 model, in 2019, enrolment rates in public schools were 9.8, 72.9, 15.0, 1.1 and less that 1.0 percent respectively (MoEST, 2019). In terms of gender, secondary school enrolment of girls constituted 51.3 and 53.5 percent of all children in public and private schools respectively. Private schools also follow the same system except that that English is used as a LoI right from the earlier levels. Private schools are, however, too demanding financially since they charge tuition fees that are generally too expensive for many to afford. According to MoEST (2019), the percentage of students attending private schools was 22. All schools are regulated by MoEST of Tanzania.

IBST and NOS: a theoretical framework

In this section, the researcher reviews the literature on the tenets of IBST and NOS. The purpose is to ensure that evaluating the extent to which IBST and NOS are supported by curriculum documents and implementation contexts is done. To achieve this, the review focuses on IBST and NOS as they are used in science education. Additionally, the aspects of NOS are discussed in relation to how they are associated with IBST.

IBST

In the context of school science, IBST is phrased differently. For instance, scholars have referred to it as 'inquiry-based learning' (Moote, 2019; Schramm et al., 2018), 'inquiry-teaching' (Jiang & McComas, 2015), 'inquiry-based science teaching' (Fitzgerald et al., 2019), 'inquiry-based science instruction' (Areepattamannil, 2012, p. 134), 'science through inquiry' (Dudu & Vhurumuku, 2012b, p. 581), 'classroom inquiry' (Dudu & Vhurumuku, 2012a, p. 150), to mention a few. Nonetheless, these variations seem to share a common message. For instance, all of them are based on the idea that science has to be taught (and learned) in schools as how it is actually practiced by professional scientists (Anderson, 2002; Cairns & Areepattamannil, 2019; Colburn, 2000; Dudu & Vhurumuku, 2012a; Jiang & McComas, 2015; Vhurumuku, 2011). In other words, teaching and learning of school science should mirror the features of 'scientific inquiry' (Capps et al., 2012, p. 292). However, this definition of IBST has been discredited for not providing guidance to teachers and students on how to practice scientific inquiry in science classrooms. In responding to this, other scholars have attempted to define IBST by stipulating specific steps and/or typologies that can be easily implemented. For instance, Fitzgerald et al. (2019, p. 544) describe four types of inquiry as summarised below;

(1) Confirmation inquiry: students are provided with the question and procedure, and the results are known in advance.

(2) Structured inquiry: students are provided with the question and procedure, but have to generate an explanation supported by the evidence they have collected.

(3) Guided inquiry: students are provided with the research question, and they design the procedure to test their question, and generate explanations.

(4) Open inquiry: students derive questions, design and carry out investigations, and communicate their results.

The first two types of inquiry are common in many science classrooms (Fitzgerald et al., 2019), and they involve learning activities such as highly structured laboratory experiments that require students to follow steps outlined in structured manuals. These types of inquiry neither represent true inquiry nor are they effective in developing scientific inquiry among students (Fitzgerald et al., 2019). Furthermore, while the four types of inquiry represent the levels of inquiry, with open inquiry representing the highest level of inquiry, they are very hard to translate into teachable activities. Hence, to distinguish IBST from other kinds of student-centred pedagogies, other scholars have described IBST by referring to what actually take place in science classrooms. For instance, Cairns and Areepattamannil (2019) argue that IBST is the best approach that introduces students to the real practice of science. They see IBST as involving:

> … situations where students are required to observe and question phenomena, suggest explanations for the observations they have made, design and carry out experiments that provide evidence that support or contradict hypotheses, and analyse data and draw conclusions from data (p. 3).

Similarly, according to the National Research Council (1996) – a policy advisory arm in the United States of America (U.S.A.) – IBST should be the focus of all science teaching and learning. As NRC (1996) puts it:

> When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations (NRC, 1996, p. 2).

Generally, these scholars seem to suggest that IBST involves creation of learning environments that engage students in generating questions, designing and carrying out investigations, providing alternative explanations, communicating results and doing hands-on activities. Apart from that, to engage in activities consistently with IBST, students should be actively involved as opposed to traditional classrooms where teachers dominate the process of teaching and learning (Vhurumuku, 2011). In this regard, the teacher's role is that of a facilitator. Likewise, Anderson (2002) pinpoints practices such as hands-on activities, connecting science lessons to students' real-life experiences, and active participation as important aspects of IBST. Other scholars (e.g. Lehesvuori et al., 2018, p. 1050) have gone further arguing that IBST ought to cover three main components – 'learning to do inquiry, learning about inquiry (conceptual understanding about inquiry) and learning

through inquiry', indicating that inquiry is considered as both a content and a process goal of science teaching. To this end, IBST can be defined as the teaching process involving *posing researchable questions, planning investigations, designing investigations and communicating the results of investigations.* Given their specific nature, these tenets permit the researcher to evaluate the extent to which IBST is featured in curriculum documents.

NOS

It is generally agreed that IBST cannot be achieved if students are not helped to acquire informed views of NOS (Billingsley & Fraser, 2018; Das et al., 2019; Fernandes et al., 2018; Herman et al., 2019; Leden & Hansson, 2019; Lederman et al., 2002). This is because views of NOS have been found to influence how science is conducted, accepted and interpreted (Das et al., 2019; Lederman et al., 2013; Liang et al., 2008; Temel et al., 2018). As such, science educators have emphasised on students' understanding of NOS as a means of developing a link between science and technology as well as enhancing the development of positive attitudes towards science and scientific investigations (Das et al., 2019). Similar to IBST, informed views of NOS are associated with students' familiarisation with the realities of scientific inquiry (Lederman et al., 2013). Meanwhile, amidst the debate about what constitutes NOS, scholars (e.g. Das et al., 2019; Liang et al., 2008) have attempted to propose commonly agreed aspects or assumptions about NOS. An uncommon understanding of the NOS is expected given that science tends to be influenced by religious and cultural beliefs (Das et al., 2019; Lederman et al., 2002; Liang et al., 2008). Furthermore, views of NOS have changed over time (Lederman et al., 2002, 2013), making it harder to have a universal definition or a one-size-fits-all model of NOS. However, philosophers of science, educationists and sociologists have agreed on some common features of NOS as Das et al. (2019, p. 394) have described:

> [NOS is based on the following assumptions] … scientific knowledge is tentative; empirical-based; subjective (theory-laden); partly the product of human inference, imagination and creativity; and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences and the functions of, and relationships between, scientific theories and laws

These aspects of NOS are treated as tenets and discussed in details by relating them to the tenets of IBST. The review is limited to only those aspects of NOS that have been consistently referred to in science education literature.

Tentativeness of scientific knowledge

As opposed to common notions under which scientific knowledge is treated as absolute, under this tenet of NOS, scientific knowledge is treated tentatively. That is to say, even though scientific knowledge is known to be durable and reliable (Burke et al., 2018; Das et al., 2019; Liang et al., 2008), it is not absolute and/or certain (Das et al., 2019; Lederman et al., 2013; Liang et al., 2008). This means that different forms of scientific knowledge such as laws, principles and theories are subject to modification and falsification as long as new evidence is made available (Bell et al., 2010; Chen et al., 2013; Das et al., 2019; Herman et al., 2019; Leden & Hansson, 2019; Lederman et al., 2002, 2013; Liang et al., 2008). In other words, new advances in theory and technology can change the ways we perceive reality. Several scholars (Abd-El-Khalick et al., 2017; Lederman et al., 2013; Liang et al.,

2008) concur that understanding the tentative nature of scientific knowledge constitutes an important attitude of scientists. In relation to IBST, the view that scientific knowledge is tentative encourages one to pose researchable questions and conduct investigations in order to challenge the existing scientific knowledge. In other words, there could be less room for IBST if scientific knowledge were certain and absolute.

The scientific method

The scientific method is another fascinating aspect of NOS. It is fascinating in part because there are misunderstandings regarding the presence of universal scientific methods applied by scientists when carrying out investigations (Holliday & Lederman, 2014; Leden & Hansson, 2019; Lederman et al., 2002, 2013). On the contrary, according to this tenet of NOS, there is no one single method of conducting scientific investigations (Das et al., 2019; Fernandes et al., 2018; Herman et al., 2019; Leden & Hansson, 2019; Lederman et al., 2002, 2013; Liang et al., 2008). Instead, scientific investigations might involve similar activities such as hypothesis formulation, problem identification and experimentation, but one does not need to follow the same sequence and/or steps. Different types of investigations can be carried out by using diverse methods. In addition to the scientific method involving similar activities as those in scientific inquiry, understanding that there is no single scientific method ensures that students are flexible when engaging in IBST.

Observation and inferences

This tenet of NOS demands students to make a clear distinction between observations and inferences. In other words, scientists can observe natural phenomena which are accessible to sense organs, or 'extension of the senses' (Lederman et al., 2013, p. 140). They can as well make statements about phenomena which are not accessible to the senses (Holliday & Lederman, 2014; Lederman et al., 2013). For example, students can only observe colour change using indicators but not actually how chemical reactions take place. Understanding the distinction between observations and inferences is key if students are to conduct scientific investigations. This has implications for IBST.

Scientific knowledge is theory-laden

According to this tenet, the assumptions scientists bring into scientific investigations matter significantly in determining how and what kinds of investigations they are likely to embark on. By being theory-laded, scientific knowledge is subjective. Thus, scientists are viewed as products of a particular culture. As such, scientists bring into scientific investigations their experiences, beliefs, expectations, and prior knowledge (Bell et al., 2010; Lederman et al., 2002, 2013; Liang et al., 2008). To illustrate, it is believed that scientific knowledge 'affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded' (Lederman et al., 2013, p. 41). According to Lederman et al. (2013), elements such as philosophy, politics, religion, socio-economic variables, societal values and power structures influence scientific activities. Since 'observations … are always motivated and guided by, and acquire meaning in reference to questions or problems, which are derived from certain theoretical perspectives' (Lederman et al., 2002, p. 501), scientists and students must be mindful of what assumptions they bring in. By doing so, they avoid the common belief in which science is treated as objective and uninfluenced by individual elements (Lederman et al., 2013). In relation to IBST, conducting

investigations (Cairns & Areepattamannil, 2019; Colburn, 2000; Dudu & Vhurumuku, 2012a; Jiang & McComas, 2015) must be informed by this view of NOS.

Scientific theories and laws

Previous research shows that students confuse between scientific theories and laws (Das et al., 2019; Herman et al., 2019; Lederman et al., 2002, 2013; Liang et al., 2008). For instance, students believe that, upon availability of evidence, theories will emerge from laws (Lederman et al., 2013), suggesting that theories are inferior to laws. On the opposite, laws and theories are different forms of scientific knowledge in such a way that one cannot be converted into another (Lederman et al., 2002, 2013; Liang et al., 2008). Furthermore, while scientific theories are statements that explain a natural phenomenon, scientific laws describe the relationship among variables and/or phenomena. For instance, evolution theory helps us to explain changes in heritable traits of organisms. Given that theories and laws can be sources of questions for scientific investigations, students' informed views of this tenet of NOS are very important for the successful implementation of IBST.

Scientific knowledge as a product of imagination and creativity

This tenet of NOS entails that scientific knowledge does not come from experiments and observation only, rather from human imagination, creativity and inferences (Burke et al., 2018; Das et al., 2019; Leden & Hansson, 2019; Lederman et al., 2002, 2013; Liang et al., 2008). Even though science is based on observations of natural phenomena, it also involves imagination, and creativity on the part of students and scientists. Thus, 'science, contrary to common belief, is not a lifeless, entirely rational and orderly activity in generating scientific knowledge' (Das et al., 2019, p. 394). Understanding this aspect of NOS enables scientists to consider conducting scientific investigations that are beyond human observations, hence expanding the horizons of posing researchable questions for IBST.

Materials and methods

Selection of documents

This paper relied on document analysis (Bowen, 2009; Wee & Banister, 2016) as the main research method. Document analysis enables the researcher to examine the documents in order to gain an in-depth understanding of the subject at hand. The study involved two sets of documents. The first set of documents constituted secondary school science syllabi, for both Ordinary level (O-Level)/lower secondary and Advanced Level (A-Level)/high school. In this case, a total of five (5) syllabi covering all three science subjects were retrieved from the website of the Tanzania Institute of Education (TIE) (http://www.tie.go.tz/), an agency for curriculum development in Tanzania. The syllabi contain information such as the aims of education, specific goals of science education, subject-specific and class level goals. In addition, the syllabi guide teachers' and students' day to day conduct by outlining the teaching strategies, teaching and assessment activities and resources that should be used for each lesson. Secondly, the study used the recently published national 'Basic Education Statistics in Tanzania (BEST)' (MoEST, 2019, p. 1). BEST provides national data on inputs such as enrolment rates, teacher-pupil ration, national examination results, class size, and facilities such as laboratories, to mention a few.

Thus, the document provided the researcher room to assess whether or not the material context supports the integration of IBST and NOS.

Data analysis

The theoretical framework guided the researcher in investigating the extent to which curriculum documents promote IBST and NOS. For instance, aspects such as 'planning investigations', 'conducting investigations', 'posing researchable questions', 'communicating the results' were used to investigate the extent of IBST promotion in documents. By going through the goals and strategies suggested for teaching all subjects, the researcher was able to extract information related to the tenets of IBST and NOS. For example, key phrases such as 'inquiry', 'question', 'practical', 'investigation', 'experiment' and 'scientific method' were used to guide the attention that was given in reading particular areas. Further, some of the phrases such as inquiry, question and investigations were also synonymous to each other, making the search more comprehensive. In addition, other synonymous phrases such as design, testing, research and examination were also included in the search. Word frequency count was conducted using MAXDQA 10 and the Control-Find function in order to establish the number of occurrences of selected phrases. Also, lexical search on MAXQDA was carried out to display all segments where the searched phrase occurred. This guided the researcher's focus on key segments. Further, differentiation by documents was done so that independent analysis could be performed for each subject, syllabus and syllabus sections (See Table 2). Additionally, to gain a good grasp of many aspects related to the tenets under study, the researcher read all teaching/ learning (T/L) and assessment activities suggested in the curriculum documents. This was done so as to avoid missing relevant information that are represented in the documents but written using expressions different from the pre-determined phrases. Also, by reading the table of content of BEST (e.g. Availability of science laboratories), the researcher was able to identify the aspects related to the realities of the implementation context.

Results

The status of IBST and NOS in Tanzanian curriculum documents

The analysis of curriculum documents provided mixed results regarding the extent to which the documents promote IBST and NOS. By reading the aims and goals of secondary education, subject-specific goals, the suggested teaching strategies and the time allocated for each topic, it is fair to conclude that generally IBST is more promoted as compared to NOS. For example, all the syllabi begin by stating the nine aims of education in Tanzania. One of those nine aims – to 'develop and promote self-confidence and an inquiring mind … ' (MoEVT, 2009c, p. iii) – is more consistent with the tenets of IBST. However, given their level of abstraction, it was not easy to conceptualise the aims of education in relation to specific tenets of IBST and NOS. As such, it was necessary to focus on the general objectives, competencies, suggested teaching strategies, resources and the amount of time allocated for each topic. As shown in Table 1, some of the intended learning competences reflect IBST.

Table 2. Word frequency count for selected phrases and common occurrences.

Subject	Phrase	Count in O-Level syllabi Aims/Competences/objectives	Teaching/assessment activities	Count in A-Level Syllabi Aims/Competences/objectives	Teaching/assessment activities
Physics	Inquir (y/ing)	1	3	1	0
	Investigat (e/ing)	1	41 (Carry out an investigation)	2	21
	Question	2	84 (Question and answer technique)	1	1
	Practical	2	6	1	2
	Experiment	1	72 (Conducting experiments)	2	36
	Test (/ing)	1	8 (Test as quiz)	1	1
	Research	0	0	0	1
	Design	1	7	5	7
	Nature of science	0	0	0	0
	Scientific method	1	3(The scientific method)	2	1
	Examination	0	0	0	2 (national exams)
Chemistry	Inquir (y/ing)			1	0
	Investigat (e/ing)			2	1
	Question			1	0
	Practical			2	2
	Experiment			2	33(Conducting experiments)
	Test (ing)			1	1
	Research			1	1
	Design			2	0
	Nature of science			0	0
	Scientific method			0	0
	Examination			1	2
Biology	Inquir (y/ing)	1	0	1	0
	Investigat (e/ing)	2	32	1	17
	Question	0	48 (Test as quiz)	0	52 (Teacher guided questions)
	Practical	3	25 (Practical work)	3	8
	Experiment	1	49 (Guided simple experiments)	2	19
	Test (ing)	0	12 (Test-tube, test as quiz)	2	21 (HIV testing, test as quiz)
	Research	0	0	1	2
	Design	0	10 (The teacher design investigations)	0	0
	Nature of science	0	0	0	0
	Scientific method	0	0	0	0
	Examination	1	1	1	4

Note: Researcher's own construction.

In other words, the outlined competences seem to suggest that science teaching should expose students to activities such as planning investigations, conducting investigations, communicating the results, all of which are important tenets of IBST.

Although the documents appear to promote IBST, frequency count indicated that the term 'inquiry' appears only three times in a total of 1064 teaching strategies that are listed in the O-Level physics syllabus, implying that the word 'inquiry' is not in common use. Of the three strategies in which the term inquiry appears, one states that 'the teacher through inquiry deductive to guide students to deduce the equivalent resistance for both parallel and series connections' (MoEVT, 2007, p. 39). A similar trend can be observed in other subjects (See Table 2). Nonetheless, phrases such as 'experiments', 'practical' and 'investigation' were commonly used to represent IBST-related activities. It is important to note that, as shown in Table 2, other synonymous phrases such as 'test', 'design' and 'question' were unrelated to IBST and NOS as they addressed content and teaching method aspects, for instance test-tubes, HIV testing and 'teacher using question and answer technique … ' (MoEVT, 2005, p. 103).

With regard to variation across subjects, the analysis of curriculum documents indicated that the physics syllabi were more consistent with IBST compared to chemistry and biology syllabi (See Table 2 for further details). Also, as shown in Table 1, at both levels of secondary school, objectives and teaching activities in physics syllabi are phrased in expressions such as conducting investigations, using the scientific methods, just to mention a few. While it is hard to make this generalisation without observing what actually takes place in science classrooms, it is fair to say that physics syllabi lead in supporting IBST. One possible explanation for this could be the extent to which the nature of each subject is associated with the tenets of IBST. Briefly, all the syllabi clearly state that teachers should use more student-centred pedagogy, which is a necessary condition for successful implementation of IBST. However, analysis of the syllabi's teaching activities seems to suggest that most of the investigative tasks such as experiments are

Table 1. Examples of statements of competences.

Subject	A-Level physics	A-Level biology	A-Level chemistry	O-Level biology	O-Level physics
	Design and perform experiments in mechanics, heat, vibration and waves and electrostatics. Apply theories, laws and principles of physics Use the scientific method in designing and carrying out experiments in physics (p. v)	collect, analyse and interpret data from biological scientific investigations and present them in a logical manner using appropriate methods and technology to generate relevant information Develop entrepreneurship skills in biological communication, creativity and problem solving communicate effectively using appropriate biological terminologies.	communicate well using chemical symbols, formulae and equations as well as the language of instruction	to record, analyse and interpret data from scientific investigations using appropriate methods and technology to generate relevant information in biological science Apply scientific skills and procedures in interpreting various biological data (*p*. v)	Apply scientific methods in solving problems in daily life Understanding the procedures of scientific investigation

Note: Extracted from (MoEVT, 2005, 2007, 2009a, 2009b, 2009c).

mainly teacher-directed and highly structured. For instance, generally the question for investigation and its procedures are suggested in advance.

With regard to NOS, generally, all documents seem to have ignored it altogether. For instance, the present analysis indicated that aspects of NOS such as tentativeness of science knowledge, theory-laden nature, observations and inferences, and imagination and creativity are not properly featured in the syllabi, both in written form and in the teaching/assessment activities meant to lead students acquiring them. Nonetheless, a few exceptions were noted: for instance, the O-Level physics syllabus explicitly named the scientific method as a goal and content of physics (see Table 1). Under specific objectives, students are supposed to have a good mastery of 'major steps of scientific investigation' (MoEVT, 2007, p. 4). However, the way the content outlines the steps of scientific investigation suggests that they (the steps) are systematic and linear. In describing the scientific method, the syllabi state that students will 'identify the problem, formulate hypothesis, collect data, analyse data, and communicate the results' (MoEVT, 2007, p. 4). Furthermore, the high school physics syllabus states that students should 'apply theories, laws and principles of physics'. Nonetheless a closer look at the contents under this objective suggests that it may not make students understand the distinction between theories, laws and principles. Again, only the physics syllabus has at least these few aspects related to NOS. Challenging enough, the phrase 'nature of science' is not found anywhere in all the science syllabi.

IBST and NOS: implementation challenges

With respect to coherence among the various elements constituting the curriculum, a closer look at the time allocated and the resources suggested shows that it would be hard for teachers to implement IBST successfully in the actual classroom. For instance, the Physics syllabus suggests that students should use 'circuit diagrams' (p. 39) instead of real circuits as teaching/learning resources. Another example is the high school biology syllabus (see Table 3), which suggests that students should conduct experiments using charts as resources. Certainly, the suggested resources in this syllabus cannot help students to conduct experiments as envisioned by the syllabi. Likewise, in the A-level Chemistry syllabus, the time allocated (80 min) may not be enough to meet the demands for carrying out experiments, interpreting results and producing reports. Similar cases appear 17 times in the same syllabus. Insufficient time for scientific investigations is not surprising given that instructional priorities do not favour these kinds of

Table 3. Objectives, teaching strategies and time allocations.

Specific objectives	Suggested teaching and learning strategies	Suggested resources	Time allocated
Carry out investigations on the properties of carbohydrates	Teacher to guide students to carry out investigations on the properties of carbohydrate	Maize/corn flour Glucose Cane sugar Beaker Stirrer	48 min
Explain the factors affecting the rate of photosynthesis	Teacher to guide students to conduct experiments to investigate the factors affecting the rate of photosynthesis	Chart showing the factors affecting the rate of photosynthesis	80 min

Note: Extracted from MoEVT (2009a, p. 7).

activities. To illustrate, assessment activities stipulated in the syllabi seem to suggest that conducting investigations is not a priority. For instance, in all science syllabi, only 10 percent of the assessment is allocated to tasks that relate to scientific investigations. In other words, science practical (assuming that practical sessions expose students to scientific inquiry) are given a 10 percent weight only in the assessment matrix. On the contrary, final examinations and mid-term tests, all of which are paper-pencil exams, enjoy a total of 65 percent in terms assessment weight (MoEVT, 2009a, 2009b, 2009c). That is to say, the suggested resources as assessment activities may not support the achievement of IBST goals. Generally, there is a lack of coherence among goals, teaching/assessment activities and resources. This may consequently affect the integration of IBST and NOS.

At the implementation level, some of the statistics highlighted in BEST imply that there are challenges to the integration of IBST and NOS. First, the national statistics indicate that students perform poorly in science and mathematics subjects as compared social science and language subjects. For instance, in 2018, physics and mathematics recorded the lowest pass rates at 45.5 and 20.0 percent respectively in the national examinations leading to certificate of secondary education, as compared to above 80 percent in social science subjects (MoEST, 2019). This implies that science and mathematics teachers will be under heavy pressure to raise students' achievements. Second, BEST showed that teachers are battling with larger class size. For example, the average class size for science teachers was 1:47 in 2018, with notable variations across regions. For example, in large cities of Mwanza and Dar es Salaam, teacher-pupil-ratio was at 1:63 and 1:65 respectively (MoEST, 2019).

Moreover, many secondary schools lack science laboratories. For instance, countrywide, only 64 percent of schools had at least one science laboratory in 2018. However, there are variations across region: for example, one region had only 29 percent of the required physics laboratories. To illustrate more regarding the variations across regions, the two top-performing regions in terms of national examinations (Dar es Salaam and Kilimanjaro) and the two least performing regions (Rukwa and Lindi) were selected as cases out of the 26 regions in Tanzania mainland. Results (See Table 4) indicated notable variations in the distribution of science laboratories. Additionally, laboratory shortages corresponded with poor performance and high dropout rates in the respective regions.

Discussion

This study investigated the extent to which IBST and NOS are promoted in science curriculum documents in Tanzania. Additionally, the study aimed at highlighting the challenges of integrating IBST and NOS in science education. Overall findings indicated

Table 4. Statistics on laboratories, performance and dropout rates in selected regions.

Region	Physics labs	Biology labs	Chemistry labs	Average performance rates	Dropout rates
Dar es Salaam	70.5% (258 required)	83.8% (351)	88.7% (270)	92.3%	1.3%
Kilimanjaro	57.8% (346)	69.5% (347)	69.5% (351)	85.8%	2.2%
Rukwa	43.5% (92)	39.5% (91)	40.2% (92)	73.0%	4.9%
Lindi	29.0% (124)	42.6% (122)	41.1% (124)	42.6%	5.2%

Note: Extracted from MoEST (2019).

that IBST and NOS are not given the attention they deserve. In particular, enabling students to have informed views of NOS is almost not featured in the curriculum documents. Given the numerous benefits of IBST in science education as cited in the introduction section, it is imperative that science students in Tanzania are given full opportunity to engage in scientific inquiry. In other developing countries such as Kenya (Joy et al., 2017), and Ghana (Mensah-Wonkyi & Adu, 2016), IBST enhanced students' science process skills such as measuring and inferring and understanding of circle theorem respectively. Indeed, given the benefits of IBST, several countries, e.g. the U.S.A. (NRC, 1996), and in recent years the Republic of South Africa [RSA] (Lehesvuori et al., 2018; RSA, 2008), have formally recognised IBST as an approach that should guide all science teaching and learning. For instance, following the introduction of a new physical science curriculum in 2006 which focuses on 'science through inquiry', several adjustments were made to the curriculum including integrating IBST in pre-service teacher education programmes and dedicating 40 percent of continuous assessment time to practical investigations (Dudu & Vhurumuku, 2012b, p. 581). Dudu and Vhurumuku (2012b) note that these reforms have enhanced science teachers' use of IBST in return. Similarly, if Tanzania is to succeed in practising IBST, issues related to curriculum coherence such as allocating enough time for scientific investigation will have to be addressed. Furthermore, if Tanzania wishes to realise her goals of instilling a scientific culture among citizens, instructional design should be devised to help students to develop informed views of NOS. This is because views of NOS greatly influence how science is conducted and accepted (Lederman et al., 2013; Liang et al., 2008; Temel et al., 2018). Furthermore, addressing aspects of NOS such as theory-leadenness of scientific knowledge has a potential to help students to connect between school science and indigenous knowledge and cultures (Lederman et al., 2013). To be able to achieve these goals, IBST and NOS should be formally recognised as important aspects of science education. Additionally, curriculum documents should be coherent enough to ensure that teaching and assessment activities as well as the time allocated their accomplishment support IBST and NOS related goals. Nevertheless, as the results have indicated, larger class size remains a challenge for teachers to implement student-centred pedagogy. This problem is even more serious currently as the increase in enrolment in secondary schools in Tanzania has resulted in larger class sizes of up to 100 students per class (Kinyota et al., 2019). Moreover, given the pressure from high-stake testing and an overemphasis on national examinations, many science teachers prefer lecture methods, as it ensures a larger content is covered within a short period (Kafyulilo & Tilya, 2019; Kinyota & Kavenuke, 2018; Kitta & Tilya, 2010; Mkimbili et al., 2017). Additionally, many schools in Tanzania, especially the newly established ones, are not equipped with sufficient laboratory resources to enable students to carry out scientific experiments (Kafyulilo & Tilya, 2019). Also, as Semali and Mehta (2012, p. 235) have noted, 'few or no teachers in Tanzania teach science subjects to nurture creativity, enable, or build students' capacities to become innovators or entrepreneurs'. Instead, post-independence reforms have tended to overemphasise on expanding students' enrolment in STEM. Generally, as Vavrus and Bartlett (2012) argue, these working conditions are important contextual factors that greatly influence teachers' practice and willingness to implement student-centred pedagogy.

Challenges to the implementation of IBST such as the lack of a common understanding of what constitutes IBST (Dudu & Vhurumuku, 2012a, 2012b; Nadelson et al., 2013),

science as practiced by professional scientists being above what students can manage cognitively (Dudu & Vhurumuku, 2012a, 2012b; Vhurumuku, 2011), insufficient time to engage in open inquiry (Cairns & Areepattamannil, 2019; Jiang & McComas, 2015; Vhurumuku, 2011), and high stakes examinations (Cairns & Areepattamannil, 2019) will be expected. With respect to NOS, challenges such as students (Das et al., 2019; Lederman et al., 2002; 2013; Liang et al., 2008) and teachers (Herman et al., 2015; Leden & Hansson, 2019) having naïve views of NOS have been noted elsewhere. Additionally, the results of the present study are supported with earlier studies (e.g. Billingsley & Fraser, 2018; Herman et al., 2019) which found that NOS is not considered by teachers a priority of instructional objectives. Likewise, several scholars (e.g. Das et al., 2019; Leden & Hansson, 2019; Liang et al., 2008) have noted that the teaching of NOS is not given its due attention in curriculum documents. Despite these challenges, it is still possible to come up with an IBST and NOS model that can work in Tanzania by carefully studying and working on the challenges inherent in the Tanzanian context. To achieve that, coherence in curriculum documents will be the first step since it is curriculum documents which guide classroom instruction. Secondly, there is the need to address the trade-offs between enhancing students' science achievement and enabling students to acquire process skills such as scientific inquiry and informed views of NOS. In a study that involved 69 countries which participated in the 2015 Program for International Students Assessment (PISA), Cairns (2019) found that the aspect of open inquiry such as students designing their own experiments and having a debate about science investigation were negatively correlated with science achievements. Meanwhile, students arguing about science questions and drawing conclusions were not correlated with achievement. Instead, teacher-directed items such as teacher explaining how a scientific idea is applied were related to gains in science achievement (Cairns, 2019). Therefore, given that science teachers in Tanzania must aspire to raise students' science achievements, formal arrangements such as having few class hours dedicated to IBST and NOS activities each week can help to focus on these process skills. Thirdly, efforts to promote IBST and NOS in science education, as Cairns (2019) suggested, will call for proper training of teachers, both pre-service and in-service teachers. Unfortunately, teachers in Tanzania have very little access to professional development opportunities (Anangisye, 2011; Kinyota et al., 2019; Komba & Nkumbi, 2008). This challenge will have to be addressed. Science teachers will need to unlearn pre-conceived notions about teaching. This is because the teachers' beliefs about what constitutes successful teaching influence their practices (Cone, 2012; Dudu & Vhurumuku, 2012b; Hutchins & Friedrichsen, 2012). Also, given that teachers' beliefs tend to be persistent (Mesci & Schwartz, 2016), more efforts will be needed to break the bond between science teachers and the transmission models of teaching in Tanzania. Fourthly, with initiatives to reconsider the integration of indigenous science underway (Semali & Mehta, 2012), curriculum planners will have to figure out how and what models of IBST and NOS can co-exist with indigenous knowledge border crossings. For instance, responses to the Covid-19 pandemic such as using untested local herbs and sometimes ignoring medical advices, one may say, has exposed Tanzanians' lack of faith in the nature of school science and scientific investigations. Or, at least, it implies a cognitive dissonance involving the science taught in schools and the indigenous science. Fifthly, to ensure equality of students' engagement in IBST and NOS, the observed resource gap across regions, especially in the distribution of science laboratories,

will have to be addressed. Finally, language barriers need to be addressed. The use of English as a LoI has been found to be a barrier to science learning in Tanzania (Mkimbili et al., 2017; Semali & Mehta, 2012). Thus, the use of Swahili language could offer a better ground for integrating IBST and NOS.

Limitations and conclusion

Although this study highlights the status of science teaching and the challenges affecting it, with focus on IBST and NOS in a context where little research has been done, it is not without limitations. For instance, interviews with science teachers and /or observation of their classroom practice could have offered more insights regarding how teachers deal with the observed lack of coherence in curriculum documents. Thus, by using other methods such as interviews, observation and larger surveys, future studies are needed to investigate the extent to which IBST and NOS are integrated in science classrooms in Tanzania. Secondly, even though this study invigorates the debate about the best ways to teach science subjects, it does so without understanding the perspectives of curriculum planners and implementers. Therefore, future research might investigate the opinions of these important actors regarding IBST and NOS. This will be an important step in case the country needs to make necessary reforms in relation to IBST and NOS. Thirdly, the study missed an analysis from the O-Level chemistry syllabus because it could not be retrieved from the TIE website. Finally, given that the documents used were not originally intended to serve the research questions addressed by this study, misinterpretations and missing of some aspects might have occurred. However, adhering to the theoretical framework, the researcher believes, helped in minimising such effects.

To conclude, although previous studies have found that science teachers in Tanzania prefer using teacher-centred pedagogy, none of them has related the problem to lack of curriculum coherence. Thus, there is a need to revise the curriculum so that it can achieve the goals stated in it. The present study has exposed other challenges such as class size, insufficient laboratory equipment, and students' poor performance in science subjects. To engage in IBST and enable students to have informed views of NOS, these challenges will have to be addressed. More importantly, it is wise to think of a model that can work in these challenging conditions.

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