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ARTICLE

Representations of the Nature of Science in South African Physical Sciences Textbooks on Electricity and Magnetism

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Abstract

Developing students' understanding of and about science is an important educational goal. Learning the nature of science (NOS) has been recognized as a critical component of science literacy, affecting how students (our future citizens) make informed decisions. Textbooks can be useful teaching materials if the content presented aligns with curriculum guidelines, but they may not completely satisfy students' learning needs. The reconceptualized FRA to NOS (RFN) offers a framework for teachers and students seeking to unpack and construct a comprehensive understanding of NOS. The present research analysed how NOS was represented in three chapters addressing magnetism and electricity in three high school textbooks published in South Africa. Using the 11 RFN categories and four levels of information explicitness criteria as analytical tools, we found that scientific practices, scientific knowledge, and social values were the three most frequently used NOS representations. Textbook excerpts representing these three RFN categories at different levels of information explicitness were also discussed in order to show how the target RFN were represented on this topic. Chronological diagrams were employed to denote how NOS representations interacted with one another, as well as reveal the level of information explicitness. Finally, the identified learning goals proposed by the textbooks were analysed to see how the NOS-related content aligned with the learning goals from the RFN perspective.

Keywords Nature of Science · NOS · Textbook analysis · Physics education

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1 Introduction

A necessary prerequisite to addressing the goal of scientific literacy is developing students' understanding of the nature of science (NOS) (Lederman et al., 2013). As a result, for more than 100 years, NOS has been advocated for as an important curriculum goal for students studying science (Lederman & Lederman, 2014; NGSS Lead States, 2013). Lederman (1992) argued that the core of NOS includes the epistemology of science, science as a way of knowing, and the values and beliefs inherent to the development of scientific knowledge. Beyond a broad definition such as this, there have been many disagreements among philosophers, historians, sociologists, researchers, and science educators regarding the exact meaning of NOS (Lederman et al., 2013). Amongst these perspectives, one that has recently achieved prominence is the family resemblance approach (FRA), which maintains that these perspectives encapsulate other aspects of science, such as the process of inquiry, aims and values, scientific methods, politics, the economy, professional structures, advertising, and science-related commerce. In essence, other perspectives address the cognitive, epistemic, and social dimensions of science in a more holistic manner and offer a broader perspective regarding what science is about (Akgun & Kaya, 2020).

South Africa's reformed school science curriculum places a strong emphasis on this goal for students of science. Based on the Curriculum and Assessment Policy Statement (CAPS), the physical sciences promote knowledge and skills in scientific inquiry and problem solving; the construction and application of scientific and technological knowledge; and an understanding of the nature of science and its relationships to technology, society, and the environment (Department of Basic Education [DBE], 2011a). Textbooks are regarded by teachers as a key resource in advancing this goal. Thus, in view of the importance of textbooks in furthering the aims of the curriculum and the curriculum's current emphasis on NOS, the present research provides an analysis and comparison of three Grade 10 physical sciences textbooks' representations of the NOS. We selected the topics of electricity and magnetism, since knowledge in these areas provides special conditions for discussing NOS in science lessons, such as how science depends on empirical evidence (Schiffer & Guerra, 2015). In addition, historical narratives exist for these topics, and such support narratives can enhance discussions of NOS through the teaching of scientific content in a historical-philosophical approach (Klassen, 2009). Furthermore, within the South African context, electricity and magnetism is regarded as a main knowledge area and significantly weighted in curriculum coverage (18% of teaching time). McDonald (2017) indicated that "by exploring a single topic in depth, a holistic analysis can be conducted to discover which NOS aspects are highlighted, which NOS aspects are left out, and how the NOS aspects are represented" (p. 103). Accordingly, this study takes a broad and inclusive approach to analysing how various aspects of NOS are considered and practically organized in South Africa textbooks, looking specifically at the topics of *electricity* and *magnetism* in South Africa textbooks.

2 The South African Context

A key question to consider is why there has been such a drive to emphasize NOS in science teaching and learning. Research spanning three decades has made a strong case for the inclusion of NOS in the science classroom. Findings have revealed that understanding NOS assists students in forming a conceptual understanding (Songer & Linn, 1991), enables students to make informed decisions on socio-scientific issues (Driver et al., 1996), stimulates their interest in the subject (Lederman, 2007), and conveys to students a view of science as the human activity of trying to understand the physical world (Hoffman & Torrence, 1993).

This recognition of the importance of NOS is reflected in school science curricula around the world. However, of particular interest is the elevation of NOS in South Africa as a result of significant curriculum revisions due to a transformation in national politics. During apartheid, the general philosophy of education in South Africa that was fundamental pedagogics promoted a strong control over education (Le Grange, 2008). This philosophical influence was particularly evident in science, where the curriculum depicted to the student and teacher a view of science that was incompatible with NOS. There was a heavy emphasis placed on learning the products of scientific enterprise in the form of facts, concepts, principles, and laws of the physical world, depriving students of experiencing the processes of science (Taylor & Vinjevold, 1999). Thus, students encountered a very skewed perspective of NOS.

A key focus of the reformed school science curriculum in South Africa is for students to acquire an understanding of NOS. Post-apartheid, science curricula documents define scientific literacy broadly in terms of process skills, conceptual knowledge, and relationships between science, society, and the environment. Thus, there is now a more valid depiction of NOS in the curriculum. In the national Curriculum and Assessment Policy Statement: Physical Sciences (i.e. physics and chemistry) document for the Further Education and Training phase (Grades 10 to 12), there is a clear goal for students to acquire an understanding of NOS. This intention is reflected in the specific aims of the physical sciences curriculum, such as with Specific Aim 3, which states that the subject should promote "an understanding of the nature of science and its relationships to technology, society and environment" (DBE, 2011a, p. 8). It was envisaged that this focus on NOS would transform the practices of teachers from a traditional teacher-centred approach to a learner-centred inquiry-based approach where learners would acquire insight into various aspects of the NOS such as the nature of the scientific inquiry process, the epistemology of scientific knowledge, and social interactions in a scientific community (DBE, 2011a).

South African science teachers rely heavily on the textbook when teaching science. In some schools, textbooks are the only source material available to teachers (Ramnarain & Padayachee, 2015; Malcolm & Alant, 2004). Traditionally, textbooks offer teachers the comfort and convenience of having lessons planned out in advance and worksheets easily available on demand (Swanepoel, 2010). In South Africa, teachers in public schools are mandated to use textbooks from a list compiled by the Department of Basic Education. New textbooks proposed by publishers are first screened by a panel chosen by the Department before being included on the list. During the screening process, a panel of reviewers evaluates the book against criteria drawn up by the Department. Textbook studies in post-apartheid South Africa have largely focused on how successful the book is at addressing challenges posed by integration and the constitutional imperative of the recognition of diversity. For example, a large-scale study by McKinney (2005) examined 61 textbooks in use in South African primary schools. Given this state of affairs, it is necessary to analyse South African science textbooks to establish how well they affirm a key intent of the curriculum: representations of NOS.

3 Textbook Analysis for NOS

The vast majority of studies that have been done have applied the "consensus" perspective on NOS tenets as an analytical framework (Abd-El-Khalick et al., 2008, 2017; Bensaude-Vincent, 2006; McComas, 2003; Vesterinen et al., 2013). There are only a few textbook analyses that consider FRA constructs (BouJaoude et al., 2017; McDonald, 2017; Yang et al., 2020). Such analysis of science textbooks has revealed that certain FRA aspects are frequently mentioned, while others are neglected. This is attributable to the differing views and interests of authors towards NOS aspects (Abd-El-Khalick et al., 2008; Irez, 2009; McComas & Olson, 1998; Upahi et al., 2020). Commonly accepted topics include creativity and imagination in science, while the socio-cultural context of science and models used in science exploration are often omitted (Abd-El-Khalick et al., 2008; Aydin & Tortumlu, 2015; Irez, 2009). Similar studies conducted in Australia over a three-decade period that examined physics textbooks for NOS representation and curriculum balance revealed a strong focus on science as a body of knowledge, with limited emphasis on science as a way of thinking (McDonald, 2017). Abd-El-Khalick et al. (2017) found in a recent US-based science textbook analysis that less than 2.5% of the textbook pages analysed addressed NOS constructs.

A South African study on the representation of NOS in science textbooks by Padayachee (2012) indicated that despite curriculum reforms in the new era of South Africa (which advocates for learning science through inquiry), there was still a dominant theme of science as a body of knowledge, which prevailed in life sciences textbooks. A study conducted by Ramnarain and Chanetsa (2016) on the analysis of natural sciences textbooks used in South Africa revealed that these textbooks had few occurrences of NOS aspects that related to the social dimensions of science, science versus pseudoscience, and the myth of the scientific method.

4 Family Resemblance Approach to the Nature of Science

NOS has been approached variously in terms of the philosophical stance and worldview of how scientific enterprises operate. Key proponents of NOS in science education research (Abd-El-Khalick, 2012; Lederman, 2007; McComas et al., 1998) have advanced what has been referred to as a "consensus view" of NOS. According to this view, the characteristics of scientific enterprises are that scientific knowledge is tentative and subject to change, scientific knowledge is subjective, people from all cultures contribute to science, and scientific ideas are affected by their social and cultural milieus (Lederman et al., 2002; McComas & Olson, 1998). These principle statements render themselves easily adapted to NOS surveys and classroom instruction (Khishfe & Lederman, 2006; Lederman et al., 2002), but alternative approaches such as whole science (Allchin, 2011), the features of science (Matthews, 2012), FRA (Erduran & Dagher, 2014a; Irzik & Nola, 2014) and others (e.g. Wong & Hodson, 2009, 2010) demonstrate the necessity of emphasizing the multifaceted nature and complexity of the scientific enterprise. Hodson (2014) suggested that these disagreements stem from the significant differences among the subdisciplines of science in terms of the types of research questions framed, methods used, and criteria employed to establish the validity and reliability of the evidence collected.

With the goal of making NOS learning more authentic with regards to what science actually is, Erduran and Dagher (2014a) proposed the family resemblance approach (FRA) framework that was adapted from Irzik and Nola's philosophical works (2011, 2014) which described how characteristics of science might be related to or vary from one to another on the basis of Wittgenstein' idea of "family resemblance". The seemingly unrelated and discrete NOS knowledge can be coherently and interconnectedly organized by the conceptual framework, just as how knowledge in different science discipline developed in response to the efforts of scientific enterprise. FRA was later adapted into reconceptualized FRA to NOS (RFN) in order to distinguish between the application of FRA in an educational context to its philosophical counterparts (Kaya & Erduran, 2016). RFN is a holistic approach that promotes an understanding of science as a conception of dynamic cognitive, epistemic, and social-institutional systems (Akgun & Kaya, 2020). As per Fig. 1, the FRA wheel consists of 11 categories, with the inner-most level representing the cognitive and epistemic aspects of science and the outer levels indicating social-institutional elements. These categories will be discussed in "Methodology"

To better support NOS learning, RFN was purposefully planned by organizing NOS ideas into categories, valuing inter-connectedness among those categories, and taking a holistic approach to science knowledge. All of these features render RFN a framework constructive to preservice teachers' learning of NOS (Cullinane, 2018; Erduran & Kaya, 2018). An RFN-based questionnaire composed of 70 selective NOS statements from an infinite set of possibilities for each category was also developed to evaluate pre-service teachers' understanding of NOS (Kaya et al., 2019). The RFN framework has been used as an analytical tool to evaluate how curriculum standards encompass NOS ideas (Erduran & Dagher, 2014b; Kaya & Erduran, 2016; Yeh et al., 2019) and identify how NOS is represented in textbooks (BouJaoude et al., 2017; McDonald, 2017; Yang et al., 2020). It would be ideal if knowledge of and about science that is presented to students engages them to

Fig. 1 The FRA wheel: science as cognitive, epistemic and social institutional system (Erduran & Dagher, 2014a, 2014b, p.28)

construct a holistic, interconnected understanding of the topic. Thus, what and how NOS is presented in textbooks should be explored, especially as textbooks are a major learning resource for students. The present research was guided by the following questions:

1. How is RFN represented in the topics of electricity and magnetism, as presented in high school physical sciences textbooks?
2. How explicitly are the RFN categories represented across the three selected textbooks? In which parts of the textbooks are these NOS representations located?
3. To what extent did the selected textbooks strategically present the NOS-RFN ideas, aligning with NOS learning goals?

5 Methodology

To answer the research questions, we used the RFN framework to examine how NOS was represented in three high school physical sciences textbooks published in South Africa, analysing chapters addressing the topics of electricity and magnetism. Electricity and magnetism are referred as one of four "main knowledge areas" in high school physics, in contrast to (1) mechanics, (2) waves, sound and light, and (3) matter and materials (DBE, 2011a). Electricity and magnetism, in the example textbooks, were covered in three chapters on magnetism, electrostatics, and electricity (as per the standard for South Africa).

The three textbooks that formed the focus of this research appeared in a catalogue of school textbooks that had undergone screening by the South African Department of Basic Education for curriculum compliancy and were deemed appropriate for use in public schools. In order for schools to receive a government subsidy for textbook purchases, they must order those books from this catalogue. The three textbooks that were analysed were the only Grade 10 Physical Sciences textbooks listed in the catalogue. The other books on the market are essentially in the form of workbooks comprised of worksheets that learners complete. Based on their sales, the textbooks we analysed are currently the most commonly used in Grade 10 Physical Sciences classrooms. Due to this, we regard the representation of NOS in these books to be widely representative of NOS representation for textbooks used in South Africa. The lengths of the target chapters in each textbook were 30 to 32 pages. The three textbooks were published by Study and Master (Textbook 1, Kelder, 2013), Platinum (Textbook 2, Grayson, et al., 2011), and Maskew Miller Longman (Textbook 3, Dilley, et al., 2005).

5.1 Analytical Framework

To explore how NOS was represented, a codebook was constructed for three coding categories: (1) the section in which each episode was located,(2) the RFN category the episode represented, and (3) the explicitness of the information described in the RFN category. These three coding categories were borrowed from McDonald (2017), but the rubric for information explicitness was modified from the scheme proposed by Abd-El-Khalick (2013) and authors (2016). Coherence and interconnectedness are discussed below and were based on how the identified NOS representations related to one another within and across the textbooks.

We used episodes as coding units for each NOS representation identified from the textbook content. Episodes were conceptualized as meso-level units of analysis through which "thematic unity" was prioritized in text segments defined as "identical participants, time, location or global event or action" (van Dijk, 1982, p. 177). For example, a complete experiment activity (e.g. different arrangements for illuminating lightbulbs) or the history of a scientific innovation (e.g. the compass) would have been viewed as one coding episode. It was possible that an episode could have been coded as multiple RFN categories. Table 1 lists descriptions of the 11 RFN codes, including categories from the cognitive-epistemic and social-institutional systems (Erduran & Dagher, 2014a). Each identified episode was also coded according to how it was represented within various sections of the textbooks, including science content (i.e. the main narrative), science inquiry activity, historical vignette, contemporary issues vignette, or question set.

Lastly, we also analysed the NOS representations in each episode according to how explicit and consistent the information was that guided students to reflect on and think about NOS. Abd-El-Khalick (2013) used a seven-level scoring rubric (+3 to −3) to evaluate how explicitly, informed, and consistently NOS ideas were represented in textbook excerpts, corresponding to the 10 specific NOS aspects inherited from the consensus view (Abd-El-Khalick et al., 2008). It is important to note that explicitness should not to be deemed equivalent to traditional teacher-centred instruction, where the teacher directs learners towards mastering a body of knowledge or learning a skill. Rather, we assumed the position of Khishfe and Abd-El-Khalick (2002), who articulated that this approach "emphasizes student awareness of certain NOS aspects in relation to the science-based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects" (p.555).

In contrast to the refined levels anchored for NOS tenets that have pre-determined ideas, the inclusive nature of RFN categories, which accommodate relevant NOS ideas that are hard to exhaustively list, made it better to evaluate them by their explicitness and holisiticity but not consistency. Therefore, we adapted the explicitness-based scoring criteria to have four levels, based on our pilot coding practices (stage 2, as discussed below). These levels included the following: explicit and informed [+3], explicit and partially informed [+2], implicit and naïve [+1], and target NOS aspects not addressed [0]. Table 2 describes how these four levels were differentiated according to the level descriptions, examples identified in the textbooks, and explanations of how the examples corresponded to the target levels.

5.2 Analytical Procedure

A three-stage coding process was utilized to ensure the trustworthiness of the coding results for the unsystematic message structures in the textbooks. First, the first author determined 122 episode segments representing at least one distinctive but not exclusive RFN code. That is, the first author prepared ad hoc textbook segments for the second author to code. Second, the first and second authors independently coded one randomly-selected chapter across three publishers, discussed and clarified discrepancies, and reached a coding consensus. The inter-rater agreement was $\kappa = 0.68$ for the RFN categories and $\kappa = 0.57$ for information explicitness (Cohen's kappa coefficient; Cohen, 1960) before coding consensus was achieved. According to McHugh (2012), the interrater reliability for social science studies can be moderate ($0.40 < \kappa < 0.59$), substantial ($0.60 < \kappa < 0.79$), or perfect ($0.80 < \kappa < 0.100$). In the third stage, the two authors coded the remaining chapters, which yielded the reliabilities of $\kappa = 0.87$ and $\kappa = 0.70$, respectively. Any coding discrepancies were discussed and resolved between the two coders, so the rubrics were continuously

Table 1 NOS-FRA codes

Code	Description
NOS aspect	
C1 – *aims and values*	The scientific enterprise is supported by adherence to a set of values that guide scientific practices. These aims and values are often implicit and may include accuracy, objectivity, consistency, scepticism, rationality, simplicity, empirical adequacy, prediction, testability, novelty, fruitfulness, commitment to logic, viability, and explanatory power
C2 – *scientific practices*	The scientific enterprise encompasses a wide range of cognitive, epistemic, and discursive practices. Scientific practices such as observation, classification, and experimentation utilize a variety of methods to gather observational, historical, or experimental data. Cognitive practices such as explaining, modelling, and predicting are closely linked to discursive practices involving argumentation and reasoning
C3 – *methods and methodological rules*	Scientists engage in disciplined inquiry by utilizing a variety of observational, investigative, and analytical methods to generate reliable evidence and construct theories, laws, and models (TLMs) in a given science discipline; these are guided by particular methodological rules. Scientific methods are revisionary in nature, with different methods producing different forms of evidence, leading to a clearer understanding and more coherent explanations of scientific phenomena
C4 – *scientific knowledge*	Theories, laws and models (TLM) are inter-related products of the scientific enterprise that generate and/or validate scientific knowledge and provide logical and consistent explanations that develop scientific understanding. Scientific knowledge is holistic and relational, and TLMs are conceptualized as a coherent network, not as discrete and disconnected fragments of knowledge
S1– *professional activities*	Scientists engage in a number of professional activities that enable them to communicate their research, including attending and presenting at conferences, writing manuscripts for peer-reviewed journals, reviewing papers, developing grant proposals, and securing funding
S2 – *scientific ethos*	Scientists are expected to abide by a set of norms both in their own work and during their interactions with colleagues and scientists from other institutions. These norms may include organized scepticism, universalism, communalism and disinterestedness, freedom and openness, intellectual honesty, respect for research subjects, and respect for the environment
S3 – *social certification and dissemination*	By presenting their work at conferences and writing manuscripts for peer-reviewed journals, scientists' work is reviewed and critically evaluated by their peers. This form of social quality control aids in the validation of new scientific knowledge by the broader scientific community
S4 – *social values of science*	The scientific enterprise embodies various social values, including social utility, respect for the environment, freedom, decentralized power, honesty, consideration of human needs, and equality of intellectual authority

Table 1 (continued)

Code	Description
S5 – *social organizations and interactions*	Science is socially organized in various institutions, including universities and research centres. The nature of social interactions among members of a research team working on different projects is governed by an organizational hierarchy. In a wider organizational context, the institution of science has been linked to industry and the defence force
S6 – *political power structures*	The scientific enterprise operates within a political environment that imposes its own values and interests. Science is not universal, and the outcomes of science are not always beneficial for individuals, groups, communities, or cultures

fine-tuned until the boundary of each level was clearly-defined and descriptive of the corresponding episodes.

Taking two episodes as examples, experiment 1 on magnetism in textbook 1 guided students to observe: (1) how two bar magnets interacted with one another and (2) how bar magnets showed their magnetic fields through iron filings. The experiment asked students to set up their bar magnets, observe and record their findings, and develop appropriate explanations for their observations. The experiments described ideas regarding making observations, recording data, drawing patterns, and explaining the patterns observed, but the textbook did not specify why the experiment was conducted in this way. Therefore, we coded the experiment instruction as [C2-scientific practices], while the information explicitness was [level + 2]. The step-like instruction indeed engaged students to explain what was observed, but an explicit attachment addressing how each of the practices (i.e. the experiment setting, data collection, pattern analysis, and explanation development) was epistemically and cognitively interrelated was necessary. The textbook 1 authors explained the experiment in another paragraph, which we regarded as another episode. The explanations came with a diagram showing the concept of positive and negative poles on the bar magnets, which was coded as [C4-scientifc knowledge] and [level + 1]. This episode was coded as [level + 1], mainly because it explained how two bar magnets connected but did not introduce knowledge regarding the fundamental laws of magnetism.

6 Findings

Patterns from the RFN coding results were identified in order to reveal what and how NOS had been addressed. Selected excerpts and examples were also presented for the purpose of unpacking how NOS has been practically represented and discussed when woven into textbooks with other critical information.

6.1 Overview of the RFN Representations

Here, we present the coding results by chapters (i.e., magnetism, electrostatics, and electric circuits) with chronological representations. Each symbol in Fig. 2 indicates a NOS representation identified from the episodes. Symbol colours were used to mark the textbook where the coding results were obtained; numbers were used to denote the sequence

Table 2 Rubric for information explicitness levels

Level	Description
[+3] Explicit and informative	Explicit descriptions that explain an informed representation of how the science enterprise operates on the selected RFN category within the indicated context
[+2] Explicit and somewhat informative	Explicit descriptions that explain an informed but incomplete representation of how the science enterprise operates on the selected category within a context
[+1] Implicit	A limited informed representation of the target RFN category, which may cause limited or naïve inferences from the textbook materials (e.g. relevant explanations, activities, examples, or historical episodes lacking structured and reflective prompts or explicit statements)
[0] Target NOS aspect not addressed	No explicit or implicit treatment of the target RFN category or insufficient materials to make an informed judgment or convey to the reader a sense of the target RFN aspect

Modified from Abd-El-Khalick (2013) and authors (2019). (Representations could include supportive examples, such as accurate historical vignettes or other accurate illustrations) by which the representations were presented. These symbols were scatter-plotted by their information explicitness levels (y-axis) as well as section locations (e.g. [science content], [science inquiry activity]) and chapter subtopics (e.g. *magnetic field patterns*, *earth's magnetic field*) (x-axis). *Quantisation of charge* was the only subtopic discussed in textbook 1 and 2 but not so in textbook 3; therefore, very few NOS representations were identified (Fig. 2B).

Patterns of the RFN categories identified were quite consistent across the three textbooks. Figure 2A to C present the coding results according to the subtopics of *magnetism*, *electrostatics*, and *electric circuits*. Scientific practices (C2), scientific knowledge (C4), and the social value of science (S4) were found to rank as the top three RFN aspects used across the three topics (see Tables 3, 4, and 5 for a comprehensive summation results). Other NOS representations identified, though in limited numbers, included scientific methods (C3) for the subtopics of magnetism and electrostatics, and aims and values (C1), political power structures (S6), and financial systems (S7) for electric circuits. Multiple codes were possible for episodes, and thus were grouped into dotted boxes.

Chronological diagrams were created to display the identified representations and their respective features (i.e. category, location, and level of information explicitness). Scientific practices (C2) appeared frequently in [science inquiry activity] and scientific knowledge (C4) was most likely to appear in [science content]. Six out of the nine chapters began with [science inquiry activities], implying that these textbooks attempted to contextualize students' learning through questions or problems related to their lives. Textbook 3 chose to engage students in a sequence of experiments ([science inquiry activity]) on series and parallel circuits (shown as C2 ■ in sub-topic (1) in Fig. 2C) to establish students' understanding of currents and charges. Besides those placed in [science inquiry activities] and [question sets], scientific practices (C2) that were found in [science content] support students' learning of scientific practices through an understanding scientists' practices and physical engagement in those practices, respectively.

6.2 Information Explicitness

As shown in Fig. 2, more than 50% of the representations were found to convey information on an implicit level (level + 1; 70 out of 135). This increased to 87.57% when those at explicitness level + 2 were also considered. No specific patterns were found regarding the textbook structure accommodating the explication of information (e.g. more of explicit scientific practice (C2) representations occupying the section for [science inquiry activity]). Among the top three representations by number, scientific practices representations at levels 0, + 1, and + 2 comprised 26.67%, 51.8%, and 35.71%, respectively. Both scientific knowledge and social values were found in 65% of their representations carrying information at explicitness level + 1; the former had 32% at level 0 and the latter had 24% at level 2. That is, disregarding those implicitly-indicated representations comprising the majority, representations of scientific practice (C2) and social value (S4) had higher percentages at explicitness level + 2, while more scientific knowledge was scored at level 0.

We used Tables 3, 4, and 5 to summarize how these three most frequently-used RFN categories were represented at the four information explicitness levels. Only four out of 135 representations were scored at explicitness level + 3, but they did demonstrate us a way how explicit and informative RFN information could be practically attached to instructional content. Episode 1a incorporated an investigation of resistance in series and parallel circuits, guiding students to experience dynamic interactions during data collection,

Fig. 2 Coding results of the RFN representations identified in three textbook chapters related to electricity. ▶

modelling, and explanation construction, as well as a discursive practice that enabled students to validate their findings with through the norm of generalization. This experiment instruction also offered suggestion for evaluation criteria that reminded students and teachers to strengthen investigation quality, such as through the use of an apparatus, data tables, and conclusion. Episode 3a offered explicit information, present how solar energy benefits human life and engaged students to discuss how solar energy can be further using the case of the world's largest commercial solar rural electrification project in South Africa, within which aims and values (C1), social values (S4), and financial systems (S7) were also discussed. The lack of level + 3 episodes identified in scientific knowledge suggested that the core idea, theory-law-model (TLM), was probably difficult to be fully attempted since textbooks are usually written in a concise and efficient way. In general, level + 3 representations engage students to construct a coherent understanding of the target RFN in an activity or a case, throughout which students explore how key and related factors interact with one another (Table 6).

Less explicit or even implicit representations comprised the majority. The major difference between those coded at explicitness levels + 2 and + 1 was how well the essential affordances of the target RFN were partially or randomly disclosed. Regarding level + 2 episode examples, 1b addressed a nearly complete voltage measurement inquiry by offering a step-like procedure, and 3b presented the pros and cons of different electricity generation approaches but lacked opportunities to reflect upon the social utility of science. As for those at level + 1, parts of the target RFN affordances were addressed but no comprehensive conceptualizations offered, such as by engaging in observation alone in an inquiry/experiment task (1c), using diagrams to model abstract concepts in science (2b), or employing electricity in safer and more efficient ways (3c). If RFN ideas are limitedly or implicitly presented (as they were in those cases), it is possible that students may mistakenly understand observation to be a full scientific practice, lack related knowledge of what a model is, and disregard the context of scientific enterprises. Lastly, representations that were coded at level 0 were those that could have but did not disclose information regarding cognitive and epistemic aspects. For example, calculation in episode 1d and explanation responses in episode 2c could have been further elaborated upon if some core scientific practices or scientific knowledge were added.

6.3 NOS Learning Goals Identified from the Textbooks

One unique feature was that textbooks 2 and 3 explicated the learning outcomes of magnetism and electricity on the front pages of each of three chapters, but this was not the case in textbook 1. Textbook 2 briefly explained the characteristics of electricity and how it improves humans' quality of life, with indications of important milestones in electricity knowledge development (e.g. discovery timing, prevalent applications). Textbook 3 set learning outcomes, including the following: "(1) scientific inquiry and problem-solving skills, (2) constructing and applying scientific knowledge, and (3) NOS and its relationships to technology, society, and the environment" (p. 91). The first two learning outcomes covered more cognitive-epistemic categories, while the last tended to address NOS according to social-institutional elements. Textbook 3 also used a protocol-like statement (shown as below) as a strategy for highlighting the epistemic understanding of science, which it had identified as important for students to learn from the experiments/activities throughout

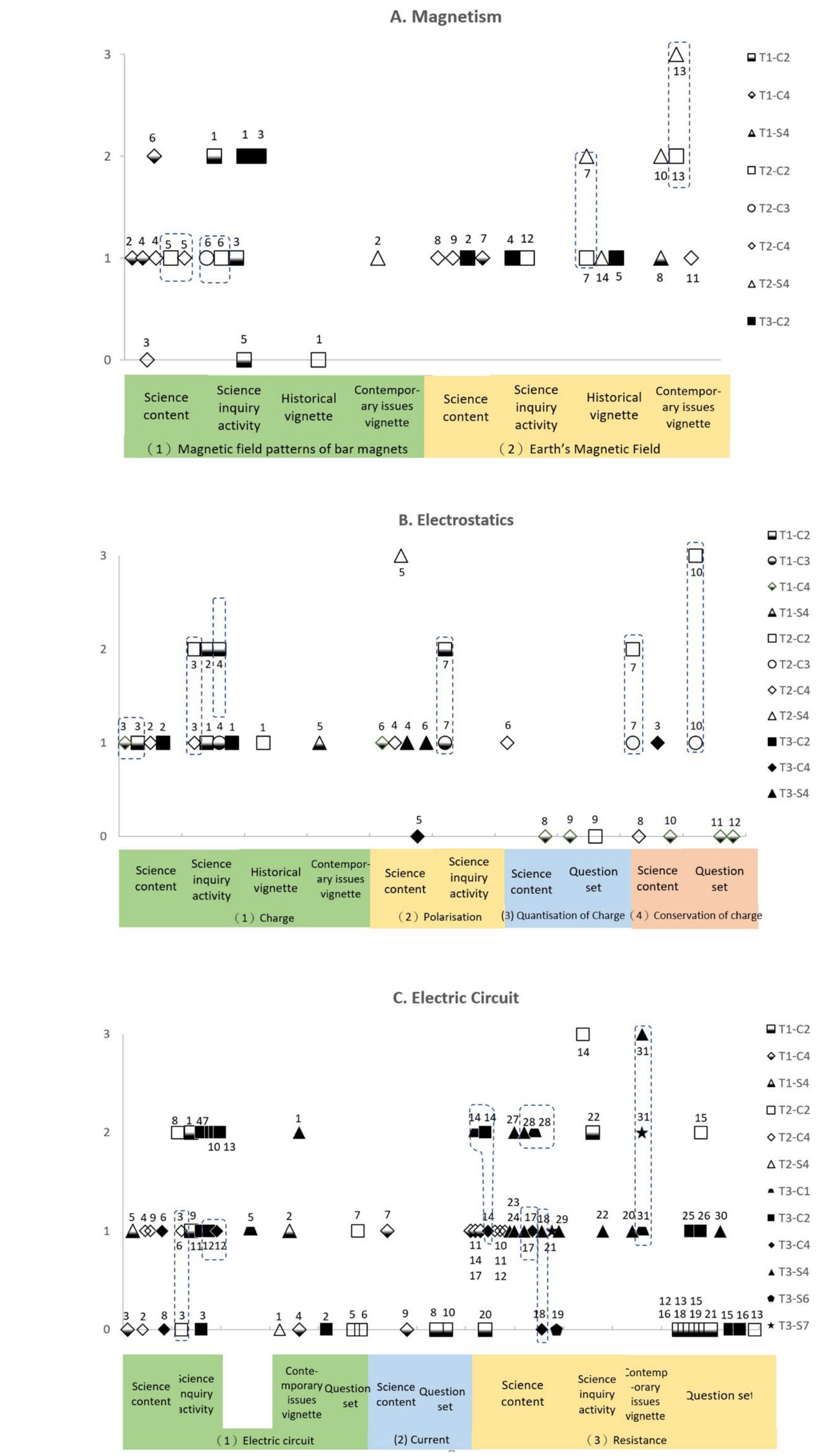
A. Magnetism
T1-C2
T1-C4
T1-S4
T2-C2
T2-C3
T2-C4
T2-S4
T3-C2
Science content
Science inquiry activity
Historical vignette
Contemporary issues vignette
(1) Magnetic field patterns of bar magnets
Science content
Science inquiry activity
Historical vignette
Contemporary issues vignette
(2) Earth's Magnetic Field
B. Electrostatics
T1-C2
T1-C3
T1-C4
T1-S4
T2-C2
T2-C3
T2-C4
T2-S4
T3-C2
T3-C4
T3-S4
Science content
Science inquiry activity
Historical vignette
Contemporary issues vignette
(1) Charge
Science content
Science inquiry activity
(2) Polarisation
Science content
Question set
(3) Quantisation of Charge
Science content
Question set
(4) Conservation of charge
C. Electric Circuit
T1-C2
T1-C4
T1-S4
T2-C2
T2-C4
T2-S4
T3-C1
T3-C2
T3-C4
T3-S4
T3-S6
T3-S7
Science content
Science inquiry activity
Contemporary issues vignette
Question set
(1) Electric circuit
Science content
Question set
(2) Current
Science content
Science inquiry activity
Contemporary issues vignette
Question set
(3) Resistance

Table 3 Percentages of NOS-FRA categories represented by textbook 1

	C2	C3	C4	S4	Total
Magnetism	3 (38%)	0 (0%)	4 (50%)	1 (13%)	8 (100%)
Electrostatics	5 (33%)	2 (13%)	7 (47%)	1 (7%)	15 (100%)
Electric circuit	14 (59%)	0 (0%)	7 (32%)	2 (9%)	22 (100%)

Table 4 Percentages of NOS-FRA categories represented by textbook 2

	C2	C3	C4	S4	Total
Magnetism	6 (33%)	1 (6%)	6 (33%)	5 (28%)	18 (100%)
Electrostatics	5 (38%)	2 (15%)	5 (38%)	1 (8%)	13 (100%)
Electric circuit	8 (50%)	0 (0%)	7 (44%)	1 (6%)	16 (100%)

Table 5 Percentages of NOS-FRA categories represented by textbook 3

	C1	C2	C3	C4	S4	S6	S7	Total
Magnetism	0 (0%)	5 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)
Electrostatics	0 (0%)	2 (29%)	0 (0%)	2 (33%)	3 (43%)	0 (0%)	0 (0%)	7 (100%)
Electric circuit	4 (10%)	14 (36%)	0 (0%)	6 (15%)	12 (31%)	1 (3%)	2 (5%)	39 (100%)

the textbook. This protocol format could be more flexible with regards to combining sub-statements relevant to the practices that will potentially be involved. Guiding statements could be made in full, partially (as shown in italics below), or in any segment combination that would epistemically highlight what to learn in the corresponding experiments/activities.

Plan and conduct a scientific investigation to collect data systematically with regard to accuracy, reliability and the need to control one variable; Seek patterns and trends in the information collected and link it to existing scientific knowledge to help draw conclusion; Apply given steps in a problem-solving strategy to solve standard exercises; Communicate information and conclusions with clarity and precision; Express and explain prescribed scientific theories and models by indicating some of the relationships of different facts and concepts with each other.

Each sub-statement of the protocol highlighted some core elements of the corresponding RFN categories. Taking the first sub-statement as an example, the keywords "scientific investigation" suggested scientific practices (C2) and "control one variable" hinted at scientific methods (C3), in addition to the keywords "accuracy" and "reliability" referencing aims and values (C1). When guiding students to learn about currents and differences in potential, textbook 3 engaged students in a systematic exploration of series and parallel circuits using inquiry activities that were mainly blended with testing on circuit boards and daily life applications (e.g. using electricity safely and economically, supporting environmentally friendly methods of generating electricity). However, it should be noted that the details of the protocol sub-statements might not be fully accomplishable as claimed. For example, several experiments in textbook 3 engaged students into testing their predictions by connecting circuits and/or reading an ammeter, but these designs did not guide students

Table 6 RFN representation examples from textbooks

Level	Scientific Practices (C2)	Scientific Knowledge (C4)	Social Values (S4)	Explanations
[+3] Explicit and informative	1a. Engage students to investigate the effects of resistors in series and in parallel. Each investigation follows the order of measurement with the ammeter and voltmeter and requires recording readings in tables and writing conclusions. Lastly, students should discuss with their peer to determine if the findings are general and then formulate personal conclusions regarding resistors. [Fig. 2C, T2#14] (pp.207-208)	N/A	3a. Case study: The world's largest commercial solar rural electrification project in South Africa, which explains project aims (providing solar power to homes, schools, and clinics) and engages students in answering questions (e.g. evaluating the possibility of using solar electricity at night or in cities). [Fig. 2C, T3#31] (p.118)	The guidance/information engages students in constructing a coherent understanding of the target RFN for an activity or a case, throughout which students explore how key and related factors may interact with one another and influence how the target RFN works
[+2] Explicit and somewhat informative	1b. Engage students to draw the magnetic fields of two bar magnets by placing them (1) separate, (2) with like poles attracted, and (3) with unlike poles attracted. Observe the patterns of iron filings on white paper where the magnet bars are. Compare the three drawings and formulate a hypothesis. [Fig. 2A, T3#3] (p.93)	2a. Remind students to recall how electrons move in magnetic fields and how they can be affected within ferromagnetic materials. Electrons can be thought of as moving in circles as a model for how magnetic fields are created. Diagrams are offered as illustrations. [Fig. 2A, T1#6] (p.103-131)	3b. Present ways of electricity generation, including a coal-fired power station with concerns regarding the greenhouse effect and nuclear power stations with concerns regarding radioactive waste. [Fig. 2C, T3#27] (p. 115)	The guidance/information engages students in constructing a broad (but perhaps incoherent) understanding of the target RFN, from which essential affordances of the RFN (e.g. the dynamics of practices, social utility) may not be fully considered or practiced

Table 6 (continued)

Level	Scientific Practices (C2)	Scientific Knowledge (C4)	Social Values (S4)	Explanations
[+1] Implicit	1c. Engage students to connect a voltmeter to each bulb and one across the cell (shown in figure). Record the voltmeter readings. Add the voltage values. What do you notice? [Fig. 2C, T3#9] (p.1)	2b. Explain magnetic fields by engaging students to examine the closeness of lines. Diagrams are offered as illustrations. [Fig. 2A, T1#4] (p.131)	3c. Present strategies for saving electricity (e.g. boiling water with an electrical kettle, not connecting more than two appliances to a single socket) and using electricity safely (e.g. unplugging a kettle before filling with water). [Fig. 2C, T3#24] (p.113)	The guidance/information offers students a single or discrete knowledge of the target RFN, by which the implicit representation may contribute to students' naïve understanding
[0] Target RFN aspect not addressed	1d. Ask to calculate equivalent resistances for different circuits. [Fig. 2C, T2#13] (p.209)	2c. Explain the potential difference in lightning using clouds as an example with a drawing offering information repeated to the text provided. [Fig. 2C, T1#4] (p.143)	N/A	The guidance/information mentions ideas relevant to the target RFN, but lacks essential features

Codes in brackets are used to refer to the symbols in Fig. 2; codes in parentheses offer the reference page information of the textbooks to investigate how and why scientists pursue robustness, high standards, or personal values through science.

7 Discussion

NOS is an important learning goal in the curriculum guidelines for South Africa (CAPS). The combined subjects of *Natural Science and Technology* in Grades 4 to 9 contextualize science learning in how science contributes to and interacts with technology with regards to human life (e.g. doing science, scientific knowledge, and science utility) (DBE, 2011b, 2011c). Such a contextualization extends and becomes even more explicit in NOS learning in the specialized subject of *Physical Sciences* offered in Grades 10 to 12 (DBE, 2011a). This study analysed chapters on magnetism and electricity for three selected Grade 10 textbooks published in South Africa and found scientific practices, scientific knowledge, and social values to be three major RFN categories represented in these chapters. However, the delivered RFN ideas were identified to reveal information at explicitness levels 1 or 2 on the 4-level scale, suggesting that these representations would benefit from the addition of explicit information. The study also provided synopsized excerpts to demonstrate how the selected textbooks represented RFN ideas at four information explicitness levels, which helped us consider how teachers could elaborate their NOS instruction on the basis of textbook information.

Scientific practices are a major topic being pursued extensively in contemporary science education (American Association for the Advancement of Science, 2009; National Research Council, 2012; Organisation for Economic Co-operation and Development, 2016) and thus an appropriate learning goal for Grades 4 to 12 in CAPS. Aligned with the goal of “making learners aware of their environment and to equip learners with investigat[ive] skills” in Physical Science for Grades 10 to 12 (DBE, 2011a, p.8), the analysed chapters showed an extensive use of representations of scientific practice and approximately 30% conveyed explicit information (beyond level + 2). The protocol statement can be viewed as a comprehensive principle of scientific practices, which textbook 3 defined and used to guide students in developing an epistemic understanding of science. The combinational format enables students to map features of scientific practices at a higher level and with some cohesiveness. Engaging students in examining how statements are adapted from the protocol and practically designed in experiments/activities is constructive to their epistemic understanding because it encourages them to examin features of science from both domain-general and domain-specific aspects (Irzik & Nola, 2014; Kaya et al., 2019).

Electricity is a topic that can easily be taught in classrooms, such as with circuit board experiments that enable students to explore scientific endeavours such as argumentation and explanation throughout the processes of problem solving and knowledge building (Berland et al., 2016; Edelson, 2001; NGSS Lead States, 2013; Reiser et al., 2017) . RFN takes a broader and more inclusive approach to scientific practices defined as scientists’ cognitive and epistemic engagement leading to scientific knowledge through social certification (Kaya & Erduran, 2016). That is, RFN categories are inter-connected by nature and likely to co-exist with one another. Similar to an analysis of Korean scientific and inquiry experiment textbooks (Yang et al., 2020), this study also found certain C-E and S-I categories (i.e. scientific methods, social utility) to easily be used together with scientific practices. Therefore, a holistic and inter-connected NOS instruction with a focus on scientific practices can be unpacked according to the scientific methods they may follow (i.e.

subject-general and subject-specific), research purposes and values to which they adhere, scientific knowledge they build upon and for, and contextual influence shaped by the scientific enterprise and whole of society (Erduran & Dagher, 2014a; Kaya & Erduran, 2016; McComas, 2008; Osborne et al., 2003).

Scientific knowledge was found to be the second-most popular RFN category, mainly at levels 1 or 0 (97%) and fixated on science content. This was not surprising, since most science textbooks present scientific knowledge in a concise and efficient way. In contrast to the property characteristics of scientific knowledge development such as tentativeness and subjectivity regarding change (Lederman et al., 2002; Liang et al., 2009) , the RFN framework focuses on how scientific knowledge grows from discrete to indiscrete forms (i.e. theory-law-model) as the outcome of scientific inquiry. Taking models as an example, it is common to see textbooks present abstract, invisible concepts via diagrammatic models or algebraic forms, but their functions and roles in knowledge evolvement may not be explicitly indicated. Many textbooks choose to present scientific laws (e.g. Ohm's laws) in narrative fashion with diagrammatic models alongside (i.e. textbooks 1 and 2), but textbook 3 used a series of current and parallel circuit experiments to support the narrative. To understand the nature of scientific knowledge, instruction design should be extended beyond inquiry tasks, and the focus should be redirected to how scientists use and construct scientific knowledge, not merely on the content level but also on the epistemological level of knowledge evolvement (Lederman, 2019; National Science Teachers Association, 1982).

Magnetism and electricity are good physics topics for developing students' understanding of NOS, since discussions can centre on the discovery history of electromagnetism, history of how current theories were developed from known laws, and scientists' efforts to develop new theories by seeking certifications within the scientific community (Guisasola et al., 2005; Schiffer & Guerra, 2015). Niaz (2014) argued that most high school and university science textbooks lack the historical perspective required for students to acquire an understanding of "the dynamics of scientific progress," and are likely to avoid addressing difficult but critical concepts (e.g. Millikan and Ehrenhaft's oil drop experiment). The textbooks analysed here addressed magnetism and electricity from the perspective of "science utility", as suggested by the CAPS, but lacked discussion of how electromagnetism developed from scientists' efforts to derive theories by explaining observed phenomena and modifying laws according to new evidence. Moreover, the socio-institutional aspects of modern electromagnetism would also be worthy of discussion (e.g. scientists being sceptical or open to research findings, research certification/dissemination/accumulation, the impacts of Royal institutes or universities on science development in the eighteenth and nineteenth centuries).

In viewing of the gap between the importance recognized in curriculum standards and less or ineffective instruction found in classrooms (Abd-El-Khalick et al., 1998; Herman et al., 2017; Lederman, 2007), textbooks and teacher manuals play important roles in how teachers support students' NOS learning (Stern & Roseman, 2004). However, the information textbooks present is connected to the authors' knowledge of and about NOS, and sensitive to the authors' interpretation of the curriculum as well as their world view, values, and presuppositions (Leite, 1999). This study used the RFN framework as an analytical tool for textbooks, but it can also be useful in instructional design. First, those repeatedly presented in textbooks offer resources for teachers to employ in building students' NOS learning, but those which are not or less informed may also deserve teachers' consideration in their instruction. All categories in the RFN framework are presumed to be involved in the process of developing scientific knowledge, but in reality, teachers must be decisive regarding what is essential to the issue of concern and deserves to be presented during limited class hours. Second, the RFN framework is unique to other NOS frameworks (e.g. Allchin, 2011; Lederman, et al., 2002), since it encourages students to construct an epistemic level of NOS understanding through organizing topic-specific or topic-general NOS ideas, as well as be aware of how these ideas are interconnected (Dagher & Erduran, 2016; Erduran & Dagher, 2014a; McDonald, 2017). It would be useful if teachers investigated how different RFN representations are allocated across topics and discuss how these ideas can be strategically arranged by their complexity and inter-connectedness.

8 Conclusion

The substantial emphasis on cognitive-epistemic aspects with limited engagement of socio-institutional issues was similar to what was seen in previous science textbook analyses (McDonald, 2017; Yang et al., 2020), though many countries have begun paying more attention to the socio-institutional aspects of their national curriculum documents (Yeh, et al., 2019; Kaya & Erduran, 2016). Olsen (2018), in his international curriculum guideline comparison study, indicated that South African curriculum guidelines lack strong support for NOS instruction (e.g. NOS ideas in allocated time). The findings indicated comparatively few and invariant types of social-institutional categories, implying that textbook authors may adhere to unclear definitions of NOS in curriculum guidelines, or pay limited attention or have only rudimentary knowledge of the depth of NOS. Consequently, the quality of NOS instruction is threatened, especially when South African teachers depend too heavily on textbooks (Ramnarain & Chanetsa, 2016; Olsen, 2018). Therefore, the RFN framework can be used as an analytical tool for curriculum guidelines and textbooks and in pre-service teacher education (Erduran & Kaya, 2019).

Textbooks can be useful materials for teaching and learning, but they should not be the only resource employed. With limited instructional hours, teachers must be very selective regarding what and how NOS ideas are taught. Although this study is limited by the single topic and country in question, textbooks can be viewed as a bridge that connects NOS learning content, curriculum guidelines, teachers, and students. Thus, it is important that teachers to be empowered with the knowledge of what and how NOS instruction can be designed and implemented in a cohesive and interconnected fashion. Curriculum guidelines and textbooks can be revised once more teachers understand how to guide students to construct their understanding of science.

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Declarations

Ethics Approval Ethics approval for survey studies is not required.

Consent to Participant Informed consent was obtained from all individual participants included in the study.

Consent for Publication The authors affirm that human research participants provided informed consent for the survey data to be analysed and presented.

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