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Exploring the inclusion of nature of science in biology curriculum and high-stakes assessments in Hong Kong: epistemic network analysis

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Abstract:	Nature of science (NOS) becomes one of the major emphases in curriculum and assessment. This study explores what and how NOS is included in the Hong Kong biology curriculum and seven-year high-stakes assessments. Although there are different conceptualizations on the definition of NOS, the family resemblance approach (FRA) is used to analyze the inclusion of NOS in the curriculum and the high-stakes assessments. In FRA, NOS comprises a cognitive-epistemic system and a social-institutional system. There is a total of 11 categories in these two systems and these categories are interconnected with one another. By adopting Epistemic Network Analysis (ENA), the frequency of connections among these NOS categories in the curriculum and the high-stakes assessments can be visualized and compared. This study reveals three major findings: (1) both the curriculum and the high-stakes assessments neglect the NOS categories in relation to the social-institutional system; (2) the NOS categories included in the curriculum are not aligned with those included in the high-stake examinations; (3) the high-stakes examinations require students to demonstrate their NOS understanding using a limited range of skills in a limited range of contexts. Implications on the design of curriculum and assessment items will be discussed.

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Abstract

Nature of science (NOS) has become one of the major emphases in curriculum and assessment. This study explores *what* NOS is included and how this is achieved in the Hong Kong biology curriculum and seven-year high-stakes assessments. While conceptualizations of the official definition of NOS differ, this study employs the family resemblance approach (FRA) to analyze the inclusion of NOS in the curriculum and the high-stakes assessments. In FRA, NOS comprises a cognitive-epistemic system and a social-institutional system. There is a total of 11 categories in these two systems and these categories are interconnected with one another. By adopting Epistemic Network Analysis (ENA), the frequency of connections among these NOS categories in the curriculum and the high-stakes assessments can be visualized and compared. Two main similarities are observed when comparing the epistemic networks of the curriculum and the high-stakes assessments, as follows: (1) a greater emphasis on the cognitive-epistemic rather than the social-institutional system; (2) the rarity of connections between categories in the social-institutional system. However, the high-stakes assessments differ from the curriculum in that they have more connections between the cognitive-epistemic system and the social-institutional system. Moreover, assessment items in the Hong Kong biology examinations involve a limited range of contexts and skills. Implications for the design of curriculum and high-stakes assessments will be discussed.

Keywords:
Nature of science, family resemblance approach, epistemic network analysis, assessment, curriculum

1. Introduction

One of the major goals in science education is to promote scientific literacy (CDC & HKEAA, 2007; AAAS, 2009; NGSS States, 2013), and the Nature of science (NOS) is an essential component of such literacy (CDC & HKEAA, 2007; Hodson, 2014; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). To promote scientific literacy, , NOS should be at the heart of both the science curriculum and assessment. Curriculum documents issued by the government guide teachers on how to include NOS instruction in their science classrooms, while examinations followi the requirements set by the curriculum documents inform teachers as to which targeted NOS ideas should be learned (Hodson, 2014).

One problematic aspect of NOS education is that although it constitutes a major instructional aim in curricula around the world (CDC & HKEAA, 2017; DOE, 2014; NRC, 2012), a majority of students still hold an uninformed and incomplete understanding of NOS (Khishfe & Lederman, 2007; Lederman et al., 2002). As Clough and Olson (2007) argued, curriculum and assessment advise what NOS should be taught and how NOS should be assessed. It has been shown that curriculum materials reflect an incomprehensive NOS understanding, particularly regarding the sociology of science (Kaya & Erduran, 2016; Yeh, Erduran, & Hsu, 2019). Other research studies have revealed an inconsistent conception of NOS (Abd-El-Khalick, Waters, & Le, 2008),. Accurate curriculum materials can promote teachers' science content and pedagogical content knowledge (Davis & Krajcik, 2005), while poorly-designed curriculum materials could possibly impede teachers' knowledge of *what* to teach and *how* to teach. Given the importance of curriculum materials in science education, research efforts have been generated to study the alignment of two different curriculum materials, such as the alignment of government curriculum documents and textbooks (Cheng & Wong, 2014). These often overlook the alignment of official curriculum documents and high-stakes assessments in terms of their inclusion of NOS.

Teachers will consider NOS an important component of science education if high-stakes assessments include items that assess students' NOS understanding. In Hong Kong, the public examination Hong Kong Diploma of Secondary Education Examination (HKDSE) has in its biology paper items assessing stuents' understanding of NOS every year (HKEAA, 2012; HKEAA, 2013; HKEAA, 2014; HKEAA, 2015; HKEAA, 2016; HKEAA, 2017; HKEAA, 2018). Wan and Wong (2017) conducted interviews with Hong Kong teachers, and report that one reason that all biology teachers within the interview sample consider NOS a crucial instructional outcome is the high-stakes assessments. It shows that the inclusion of NOS in high-stakes assessments can encourage teachers to devote more curriculum time to its teaching. Past studies also evidenced that, in addition to the curriculum, high-stakes assessments can also drive *what* and *how* science teachers teach (Jonsson & Leden, 2019). Although several researchers have suggested methods to measure students' NOS understanding (Allchin, 2017; Clough, 2011; Lederman, Bartos, & Lederman, 2014), no study currently considers the conceptualization of how the "authentic" high-stakes assessments examine students' NOS understanding.

This paper aims to contribute to the clarification and expansion of how NOS can be conceptualized in science classrooms for meaningful teaching and assessment, particularly through the design of curriculum and high-stakes assessments. Researchers commonly posit that apart from curriculum documents, the design of teaching and assessments in classroom can be affected by high-stakes assessments (Black, 1995; Brookhart, 2010; Erduran, Cullinane, & Wooding, 2019). More importantly, this paper also explores how the government documents and high-stakes assessments align with each other. Teachers sometimes see high-stakes assessments as a proxy for the national curriculum (Jonsson & Leden, 2019). This might raise questions on whether curriculum and high-stakes assessments should be considered as separate or cooperative efforts in driving NOS instruction.

The conceptual framework used in this study is the reconceptualized family resemblance approach (FRA) of NOS (Erduran & Dagher, 2014). There have been ongoing debates on "what NOS is" or "what epistemology of science is" (Allchin, 2011; Erduran & Dagher, 2014; Lederman et al., 2014; Matthews, 2012, for example, whether or not NOS should be a list of declarative statements (Allchin, 2011; Smith & Scharmann, 1999; Wong & Hodson, 2009) or the features of science taught to students be limited to specific disciplines (Irzik & Nola, 2011). The FRA offers 11 categories that "consolidate the epistemic, cognitive and social aspects of science in a wholesome, flexible, descriptive but non-prescriptive way" (Erduran & Dagher, 2014, p. 24). It can capture a "meta-level characterization of the key categories related to science in a broad sense" (Erduran & Dagher, 2014, p. 25). This study uses the FRA categories to study *which* NOS is included in the curriculum and the examinations in Hong Kong, as well as *how* NOS is assessed in these examinations. A more innovative qualitative data interpretation approach, Epistemic Network Analysis

(ENA) was used to visualize the frequency of connections between categories (Shaffer, 2017). The findings suggest that curriculum and high-stakes assessments can include a wider range of NOS categories, and the high-stakes assessments can probe into a wider range of students' skills in eliciting their NOS understanding.

2. Literature Review

2.1 Nature of Science

Nature of science (NOS) is an essential component of scientific literacy (CDC & HKEAA, 2007; Hodson, 2014; Lederman et al., 2002). Driver, Leach, Millar, and Scott (1996) have presented five arguments on the importance of understanding NOS, categorised as follows: (a) making sense of the process of science; (b) making decisions on socioscientific issues; (c) valuing science is fundamental to contemporary culture; (d) recognizing the norms of the scientific community; (e) facilitating the learning of science content. Owing to its importance in enhancing students' scientific literacy, NOS has generated significant research efforts in debating an agreed NOS definition and how it should be included in curriculum and assessment.

Nature of science (NOS) commonly refers to the epistemology, values and beliefs of scientific knowledge derived from the process of doing science (Lederman, 1992). Lederman et al. (2002) suggested a shared wisdom of NOS among different researchers. A number of NOS aspects were considered to be developmentally appropriate to be taught to high school students (Lederman et al., 2014): scientific knowledge is tentative (subject to change); creative (comprises innovation in data analysis and method of inquiry); empirical (based on observation); socially and culturally embedded; and theory-laden (prior knowledge guides scientists' work). Additional important aspects include the distinction between observation and inference, the distinction between theories and laws, social dimension of science and the lack of a universal scientific method. However, Wong and Hodson (2009) disagreed with the "consensus view" from Lederman et al. (2002), as this "consensus view" neglected the importance of learning the authenticity of the scientist's work and the connection between science and society. For example, under the framework from Lederman et al. (2002), the importance of ethics and technology innovations for the development of science was downplayed. Moreover, some social practices of scientists such as seeking funding, collaboration, competition, and peer review processes are also downplayed under their framework (Hodson & Wong, 2014). To address a complete NOS understanding in *depth* and *breadth*, Allchin (2011) suggested "whole science" as a theoretical perspective. He justified that NOS should not be a list of declarative statements but should be applied to a broader social context. Similarly, Matthews (2012) also argued that students should understand the processes, institutions and social contexts in which scientific knowledge is generated, instead of reciting declarative statements. Therefore, he suggested that students learn "features" of science rather than "nature" of science. This can avoid the misunderstanding that NOS is merely declarative in nature. Smith and Scharmann (1999) also shared a similar viewpoint that students should apply their NOS understanding to the evaluation of knowledge claims.

As a result, there were two dilemmas when conceptualising NOS for effective curriculum standards and assessments. Firstly, the number of features of NOS should not be too exhaustive to prevent easy access for teachers and professionals developing curriculum materials. (Yeh et al., 2019). Secondly, NOS understanding should not be prescribed as a list of declarative statements (Allchin, 2011; Matthews, 2012; Smith & Scharmann, 1999; Wong & Hodson, 2009).

Erduran and Dagher (2014) reconceptualized Wittenstein's generic definition of the family resemblance approach (FRA) to NOS from Irzik and Nola (2011) to resolve the above dilemmas. Initially, Irzik and Nola (2011) used FRA to differentiate similarities and differences among all science disciplines, so that it can capture the domain-general and the domain-specific features of NOS. For example, in astronomy, scientists rely on observation in non-manipulative experiments (Erduran, Cullinane, et al., 2019) to generate knowledge, but it is different in other science disciplines. From the perspectives of FRA, science has a cognitive-epistemic system and a social-institutional system: the cognitive-epistemic system contains aims and values, methods and methodological rules, practices and knowledge; the social-institutional system contains scientific ethos, professional activities, social certification and dissemination, and social value (Irzik & Nola, 2014). Erduran and Dagher (2014) added three more categories that were deemed important in science education: "social organizations and interactions", "political power structures" and "financial systems". These categories can provide a framework for students to reflect how societal and cultural forces drive the development of science. In Erduran and Dagher (2014)'s reconceptualization, an FRA wheel is created to provide a framework describing how students think and act like scientists within the scientific setting and how their work can be extended to the broader social context. In this FRA wheel, the inner part contains categories belonging to the cognitive-epistemic system and the outer circle contains those belonging to the social-institutional system (see Table 1 for the definition of categories). This two-level system can facilitate the design of teaching intervention in which learners first learn the epistemology of science and how science works, and extend their appreciation and understanding of science to a broader social context, such as the role of political, social and financial systems in shaping scientific developments of society (Erduran & Dagher, 2014). According to Dagher and Erduran (2016b) (also cited in Kaya and Erduran (2016)), the previous concerns about NOS were acknowledged in the reconceptualized FRA: (1) progressing from learning disparate NOS statements to thinking of NOS as a broader concept in the cognitive-epistemic system and the social-institutional system; (2) more connections between NOS ideas as delineated by the interconnections between categories; (3) more emphasis on the NOS categories in the social-institutional system such as scientific ethos, professional activities, social certification and dissemination and social value.

Table 1. Reconceptualized FRA categories (from Erduran and Dagher (2014)

Aims and values	The scientific enterprise is underpinned by adherence to a set of values that guide scientific practices. These aims and values are often implicit, and they may include accuracy, objectivity, consistency, skepticism, rationality, simplicity, empirical adequacy, prediction, testability, novelty, fruitfulness, commitment to logic, viability, and explanatory power.
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, modeling, and predicting, are closely linked to discursive practices involving argumentation and reasoning.
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 in a given science discipline, which are guided by methodological rules. Scientific methods are revisionary in nature, with different methods producing different forms of evidence, leading to clearer understandings and more coherent explanations of scientific phenomena.
Scientific knowledge	Theories, laws, and models (TLM) are interrelated products of the scientific enterprise that generate and/or validate scientific knowledge and provide logical and consistent explanations to develop scientific understanding. Scientific knowledge is holistic and relational, and TLM are conceptualized as a coherent network, not as discrete and disconnected fragments of knowledge.
Professional activities	Scientists engage in several professional activities to enable them to communicate their research, including conference attendance and presentation, writing manuscripts for peer-reviewed journals, reviewing papers, developing grant proposals, and securing funding.
Scientific ethos	Scientists are expected to abide by a set of norms both within their own work and during their interactions with colleagues and scientists from other institutions. These norms may include organized skepticism, universalism, communalism and disinterestedness, freedom and openness, intellectual honesty, respect for research subjects, and respect for the environment.
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
Social values of science	The scientific enterprise embodies various social values including social utility, respecting the environment, freedom, decentralizing power, honesty, addressing human needs, and equality of intellectual authority.
Social organizations and interactions	Science is socially organized in various institutions including universities and research centers. 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 institute of science has been linked to industry and the defense force.
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.
Financial systems	The scientific enterprise is mediated by economic factors. Scientists require funding in order to carry out their work, and state- and national-level governing bodies provide significant levels of funding to universities and research centers. As such, these organizations have an influence on the types of scientific research funded, and ultimately conducted.

2.2 NOS in Science Curriculum

NOS has been advocated in several curricula, becoming one of the major curricular emphases and learning targets in science education around the globe (CDC & HKEAA, 2007; Kaya & Erduran, 2016; Yeh et al., 2019). However, students often hold an incomplete understanding of NOS (Khishfe & Lederman, 2007; Lederman et al., 2002). Some argued that the design of curriculum and assessment could impact *which NOS is taught* and *how* such teaching occurs (Hodson, 2014; Meichtry, 1993).

A number of studies have shown the potential of FRA in analyzing the inclusion of NOS in curriculum materials (Kaya & Erduran, 2016; McDonald, 2017; McDonald & Abd-El-Khalick, 2017; Yeh et al., 2019). Kaya and Erduran (2016) find that the Irish and Turkish curriculum comprised several statements relating to science as a cognitive-epistemic system but underemphasizing science as a social-institutional system. They also reveal that the Irish curriculum covered the "scientitifc ethos" while the Turkish curriculum covered the "social organizations and interactions". Similarly, Park, Yang, and Song (2019) analyze the number of statements in Korean physics textbooks that address different NOS categories. Using FRA as a theoretical framework, their study identifies that most textbooks did not cover the wider social, economical and political mechanism of the scientific enterprise. In these two studies, the use of FRA enables a finer differentiation of which components of science as a social-institutional system were lacking in the curriculum documents. The social-institutional aspects suggested by Lederman et al. (2014), such as "social dimension of science", provide limited analytical breadth in relation to the nature of scientific enterprise.

However, the above studies cannot capitalize on the strength of the FRA framework, since they focus solely on the simple presence or absence of NOS categories in curricula or the number of statements that fall into an NOS category. In this framework, epistemic and social aspects interact, providing a connected account of the characteristics of science (Dagher & Erduran, 2016a). Therefore, researchers who adopt the FRA framework should consider how epistemic aspects and social aspects connect with each other to form a meaningful learning network. An example of this is the study carried out by Yeh et al. (2019). Using the FRA framework to analyze two Taiwannese science curricula, their research is grounded in an innovative perspective, namely, that NOS categories should be embedded in curriculum benchmarks in a coherent manner. They look at which NOS categories were connected in each benchmark. Their findings reveal that the components in the social-institutional system rarely connect to those in the cognitive-epistemic system.

This paper adopts the FRA framework as the theoretical framework because (1) it aligns with the aims of the Hong Kong curriculum and assessment; and (2) the "porous" character of FRA categories allows students to appreciate the interaction between epistemic aspects and non-epistemic aspects of science (Erduran & Dagher, 2014; Park et al., 2019). The aims of the Hong Kong biology curriculum are to help students "construct and apply knowledge of biology, understand the nature of science in biology-related contexts" and to help students "be aware of the social, ethical, economic, environmental and technological implications of biology, and be able to make informed decisions and judgments on biology-related issues" (CDC & HKEAA, 2017, p.4). These aims align with the notion of FRA which was developed to promote contextualized and holistic understanding of science (Erduran & Dagher, 2014). Instead of learning the nature of biology as declarative statements, the curriculum aims to extend students' understanding of the epistemic aspects of biology to a wider social context. As a result, FRA offers a solid framework to examine the articulation of NOS aspects in the Hong Kong biology curriculum.

To maximize the strength of the FRA framework, the work presented here uses an innovative discourse analysis approach, Epistemic Network Analysis (Shaffer, 2017), to quantify the frequency of connections between NOS categories in the Hong Kong biology curriculum. It is essential to visualize the NOS categories using an epistemic network in the curriculum because (1) NOS represented in the curriculum should not be treated as disparate statements but interrelated categories and (2) this aids comparison of connections between NOS categories in curriculum documents and other sources of science education materials (see Section 3 for more details of Epistemic Network Analysis).

2.3 NOS in Science Assessments

Few empirical studies exist on how NOS should be assessed in both formative and summative assessments. In particular, there are no studies that use FRA as a theoretical lens to explore how students' understanding of NOS can be evaluated in summative assessments (Erduran, Daugher, & McDonald, 2019). Such studies can provide initiatives for prioritising NOS education. Two local empirical studies reveal that the inclusion of NOS in summative assessments provided motives for teachers to teach NOS in their science lessons (Cheung, 2018; Wan & Wong, 2017). Therefore, the context of Hong Kong biology examinations provides an authentic account of how students' understanding of NOS can be evaluated.

The framework from Allchin (2011) (also in Allchin (2012)) is useful for exploring how NOS can be assessed in the Hong Kong biology assessments. He states that assessments should not just ask students to recall and comprehend NOS understanding. Instead, drawing on Bloom's (1956) taxonomy, he suggests that assessments should provide opportunities for students to apply, analyse and evaluate NOS understanding. His notion forms the following conceptual framework to analyse the type of NOS-related questions in high-stakes assessments:

- *knowledge of NOS*: to recall the definition of NOS categories;
- *comprehension of NOS*: to summarise the meaning of NOS categories;
- *application of NOS*: to apply understanding of NOS categories to a context
- *analysis of NOS*: to analyse how different NOS aspects are related to each other to explain a situation
- *evaluation of NOS*: to justify the importance of the feature of NOS to the development of science and society

Moreover, assessment items of NOS should not only be embedded into the context of history and philosophy of science, as students should be equipped with the skills and abilities to draw on their NOS understanding in a wide range of contexts. Allchin (2011) highlights the need to assess students' NOS understanding in authentic contexts, such as socio-scientific issues in magazine and newspaper. This will help students draw on their life experiences when taking part in assessment of NOS. Apart from issues related to daily life, assessments of NOS can also be embedded in the context of inquiry and history and philosophy of science (Clough, 2011; Clough & Olson, 2007). For instance, students' understanding of science methods and scientific practices can be assessed in the context of how Darwin observed species, proposed explanations of structural adaptations of species and argued for his explanation (Nelson, Scharmann, Beard, & Flammer, 2019; Scharmann, 2018). Our high-stakes examinations should not only encourage students to demonstrate their NOS understanding in one single specific context, such as history and philosophy of science, but also should allow students to utilize their NOS understanding in "whole science" (Allchin, 2017).

To date, there is a dearth of literature documenting how high-stakes examinations assess students' NOS understanding. In fact, meeting the needs of public examinations can be one of the values pertinent to the teaching of NOS (Wan & Wong, 2017). Some teachers viewed teaching NOS as helping students achieve high marks in public examinations (Wan & Wong, 2017). Therefore, their methods and contents of teaching and assessment of NOS in classroom can be affected by their values as well as how public examination assessed NOS (Cheung, 2018). To improve NOS assessment in classrooms and examinations, it is crucial to investigate *which* NOS is selected and *how* it is examined in high-stakes assessments.

2.4 Research Questions

By comparing and contrasting the inclusion of NOS in curriculum and high-stakes assessments, this study may shed light on possible improvements on how curriculum and high-stakes examinations can coherently address NOS. The following research questions guide the present study:

1. *Which* NOS categories are represented in the Hong Kong biology curriculum?
2. *Which NOS categories are selected* and *how* are NOS categories examined in the Hong Kong biology high-stakes assessments? Are these NOS categories different from those represented in the Hong Kong biology curriculum?

3 Methodology

3.1 Research Context

The education system in Hong Kong changed from 3-year junior secondary education and 4-year senior secondary education to 3-year junior education and 3-year new senior secondary education. In response to this structural change, the Education Bureau (EDB) of the Hong Kong Government issued new curriculum documents in 2007 and set up a new public examination called the Hong Kong Diploma of Secondary Education Examination (HKDSE). The first cohort of students started their first year of new senior secondary curriculum in 2009. The new examination, HKDSE, commenced in 2012 and is still in use today.

NOS was one of the major emphases in the new science curriculum in Hong Kong (CDC & HKEAA, 2007 with updates in 2015). The purported aim of science education in Hong Kong is to equip students with an understanding of NOS and to help them develop scientific literacy. The curriculum conceptualizes NOS as "beliefs and attitudes towards the knowledge about the natural world, the methods and processes through which scientific knowledge is acquired, and the sociocultural and historical influences involved" (CDC, HKEAA, 2007, p.23). The EDB funded a university to conduct a project providing teacher professional development workshops on teaching and assessing NOS (Wan & Wong, 2017). Held from 2008 to 2010, this project was conducted after the curriculum had been introduced to the public.

The biology curriculum and the corresponding high-stakes assessments were chosen as this study's focus because every year HKDSE biology has questions on assessing students' NOS understanding. HKDSE Chemistry and Physics do not have many questions that explicitly assess students' NOS understanding. The Hong Kong biology curriculum, "Biology: Curriculum and Assessment Guide (Secondary 4 - 6)" (CDC & HKEAA, 2007) (with updates in 2015) and seven-year HKDSE biology public examinations were analyzed (HKEAA, 2012; HKEAA, 2013; HKEAA, 2014; HKEAA, 2015; HKEAA, 2016; HKEAA, 2017; HKEAA, 2018). Questions in the HKDSE biology public examinations were written according to the "Biology: Curriculum and Assessment Guide (Secondary 4 - 6)".

No specific NOS framework was used by the Hong Kong Education Bureau when designing the curriculum document. In other words, the NOS-related benchmarks in the sections "Learning Targets" and "Curriculum Emphasis" do not follow the framework from either the consensus perspective or the FRA perspective. For high-stakes assessments, in some past exam questions, the assessment authority uses terminologies from the consensus perspective. For example, in 2016 HKDSE, students were asked to choose which aspects of NOS are demonstrated in the story of the discovery of genetic inheritance. The marking scheme uses phrases such as "scientific knowledge is empirically based" and "doing science requires creativity and imagination" (HKEAA, 2016). These phrases are similar to those used by the researchers in the consensus perspective (see Lederman et al. (2014)). Nonetheless, some examination questions do not adopt a consensus perspective. For example, in 2012 HKDSE, students were asked "When Mendel proposed how traits are inherited, chromosomes had not yet been discovered. In your opinion, how did Mendel come up with his hypothesis? (3 marks)" (HKEAA, 2012). These questions require students to express a coherent understanding of several NOS categories in the FRA framework, namely scientific practices, scientific knowledge and scientific method. As justified in the literature review, the strength of FRA framework is to promote students' coherent understanding of the holistic and contextualized nature of science (Erduran & Dagher, 2014) and the consensus perspective distorts NOS understanding into a set of disorganized declarative statements. Therefore, the FRA framework enables researchers to explore the inclusion of NOS in both the curriculum and the high-stakes assessments.

3.2 Data Analysis

The approved teaching resource "Biology: Curriculum and Assessment Guide (Secondary 4 - 6)" listed benchmarks related to NOS in two sections, "Learning Targets" and "Curriculum Emphases". Therefore, only these two parts "Learning Targets" and "Curriculum Emphases" were analyzed (see Table 2 for the whole list of benchmarks). In these two sections, there are 39 benchmarks in total, which were then examined to see which NOS categories in FRA are present and how NOS categories are connected within one benchmark. Each benchmark was coded using the definitions in Table 1, and each benchmark may comprise one or more NOS categories. For example, in "V&A4. be aware of the dynamic nature of biological knowledge and appreciate the role of science and technology in understanding the living world", the codes "aims and values" and "knowledge" were assigned because these articulates both the tentativeness of knowledge and the values of appreciating the role of science in understanding the living world. A code-and-recode strategy was adopted through which the data was coded twice (Anney, 2014). A percentage agreement, 79%, was obtained, indicating a high level of consensus.

Similarly, questions in the seven-year HKDSE biology public examinations, together with the answers in the suggested marking scheme, were coded using the NOS categories in FRA. Multiple-choice questions were not examined because they provide limited opportunities for students to reflect their NOS understanding (Lederman et al., 2014). They do not thus feature in this study. In the first round of screening, questions explicitly assessing students' NOS understanding were selected. An explicit assessment of NOS entailed reflective prompts eliciting students' epistemological understanding of NOS categories, or inviting students to think about the context which subsequently prompts them to draw conclusions about NOS (McDonald, 2017). By contrast, an implicit assessment of NOS did not entail such opportunities for student consideration of their own epistemological understanding of NOS categories. This can be illustrated by the examples from the two questions below:

"*Suggest an in vitro experimental method that allows a direct measurement of the digestion of fat in a laboratory. (3 marks)*" (HKEAA, 2012, Paper 1B Q10(d))

"Which of the following statements about the nature of science are demonstrated in the above historical events? Put a ✓ in the space next to the statement and provide an explanation. The first one is an example for your reference. (4 marks)"

Statement	✓	*Evidence from the historical events*
Science is socially and culturally embedded.		
Science is based on evidence.		
Science knowledge is tentative and dynamic.		

(HKEAA, 2013, Paper 1B Q7(d))

The first question requires students to list the steps of an experiment measuring the amount of fat being digested in the laboratory. Although it invites students to engage in designing scientific experiments, it does not ask students to reflect on or share their NOS understanding from the inquiry processes. By contrast, the second question invites students to reflect on the NOS categories demonstrated in the historical events. Consequently, the first question may be considered implicit assessment while the second question is considered as explicit assessment. This study only selects questions that involve explicit assessment of NOS because it focuses on *which NOS is chosen for* and *how* high-stakes examinations assess students' skills in articulating their NOS understanding. A total of 11 questions were coded as "explicit" assessments.

In the second part of the data analysis, each question was given three types of codes: (1) the first considers those NOS categories in Table 1 that the question covers, and can be coded for more than one category; (2) the second type is the skills used by students to demonstrate their NOS understanding, namely to remember, comprehend, apply, analyze and evaluate; (3) the third type of code is the context embedded in the NOS assessment, including history of science, inquiry, inquiry and history of science and social science issues. The first type of code belongs to either the cognitive-epistemic or the social-institutional system. "Aims and values", "scientific practices", "methods and methodological rules" and "scientific knowledge" belong to the cognitive-epistemic system while "professional activities", "scientific ethos", "social certification and dissemination", "social values of science", "social organizations and interactions", “political power structures” and “financial systems” pertain to the social-institutional system (Erduran & Dagher, 2014) (refer to Table 1 for more details).

The following examples are the two questions that explicitly evaluate students’ NOS understanding and are used to illustrate application of the second type and the third type of codes:

“When Mendel proposed how traits are inherited, chromosomes had not yet been discovered. In your opinion, how did Mendel come up with his hypothesis? (3 marks)”(HKEAA, 2012, p. Paper 1B Q8(c))

“Give one aspect about the nature of science that can be demonstrated in the above discovery (the discovery of Hammerling) and give a reason to support your answer. (2 marks)” (HKEAA, 2016, Paper 1 Q8(c))

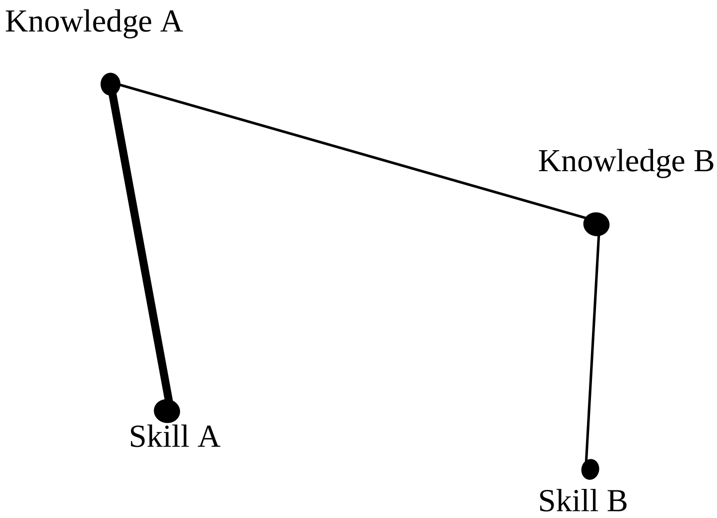
The first question assesses how students analyze their understanding of scientific methods and scientific practices and draw connections between them to explain the success of Mendel’s discovery. It also engages students in a series of questions on how Mendel carried out inquiry to identify patterns of inheritance. This question was thus coded as “analyze” for the skill, and “inquiry and history of science” for the context of assessment of NOS. The second question asks students to transfer their NOS understanding to a new context after engaging students in a series of questions on how Hammerling found the structure that stores hereditary information in algal cells. Therefore, this question was coded as “apply” for the skill, and “inquiry and history of science” for the context of NOS assessment. The code-and-recode percentage agreement is 91%, which indicates strong consensus.

3.3 Epistemic Network Analysis

Epistemic network analysis (ENA) was used to capture the NOS categories covered in the curriculum and assessments (Shaffer, 2017). It is an innovative software (http://www.epistemicnetwork.org/) in which qualitative statements in the curriculum and assessment items can be grouped together to make meaning and the connection between codes within the statement or a paragraph quantified with dimensional analysis. It is based on the notion that the structure and frequency of connections among cognitive elements, such as NOS categories, are far more important than the presence or absence of isolate elements (Shaffer, Collier, & Ruis, 2016). As Erduran and Dagher (2014) argue, NOS in curriculum and assessment should comprise coherent categories rather than isolate pieces of understanding. It therefore seems plausible that the inclusion of NOS in curriculum and high-stakes assessments can be best represented by ENA. This method of analysis and representation has been shown to be successful in visualizing the interconnections among science ideas in NOS FRA from scientists, teachers and students alike (Peters-Burton, Bergeron, & Sondergeld, 2017).

The identification of the knowledge and skills to be included in an assessment helps shed some light on how to interpret the network of ENA. It can be conceptualized as involving two types of knowledge, knowledge A and knowledge B, and two types of skills, skill A and skill B. Researchers might want to know how frequently different types of skills and knowledge are assessed in the same item. Epistemic network analysis is useful to help visualize the frequency of connections of skills and knowledge assessed in the examination (see Figure 1). As Figure 1 illustrates, the frequency of "Knowledge A" and "Skill A" being assessed in the same item is the highest, and characterized by the thickest line of connection between these two codes. Their frequency of connection is higher than the frequency of connection between "Knowledge A" and "Knowledge B", which are depicted by a thinner line of connection.

Figure 1. Epistemic network of different types of skills and knowledge assessed in an examination



To see how ENA actually works, it is first necessary to examine this project's coded file (see Figure 2). To analyze the curriculum benchmarks in the Hong Kong biology curriculum, each curriculum benchmark in Table 2 was entered an Excel file. Each benchmark was considered as one segment. Codes in Table 1 from the FRA categories were assigned to each benchmark. It should be noted that more than one code can be assigned to a benchmark. For example, the first benchmark with an "1" was input into the category "C.aims and values" because the code "aims and values" in the cognitive-epistemic system was assigned to this benchmark. In the second benchmark, "1" was input into the categories "C.aims and values" and "C.scientific practices" as the two codes "aims and valus" and "scientific practices" in the cognitive-epistemic system were assigned to this benchmark. In the context of ENA analysis, relations between categories have been specified. The co-occurrence of two NOS categories in a single segment indicates that these two NOS categories are conceptually linked (Shaffer et al., 2016). Therefore, "aims and values" are considered as having connection to "scientific practices" in the second benchmark. ENA weighs the frequency of connections between codes and visualizes the connections among codes in a network. The only network formed from analyzing the curriculum document shows how frequently NOS categories are linked to each other in all benchmarks.

Figure 2. The actual coded file of the Hong Kong biology curriculum

Section	Parts	Line	Segment	Code	C.aims and values	C.method	C.scientific practices	C.knowle	S.professi	S.scientifi	S.social c	S.social v	S.social o	S.political	S.financia
Learning Targets	K&U	1	acquire knowledge and develop an	C.aims an	1	0	0	0	0	0	0	0	0	0	0
Learning Targets	K&U	2	apply biological knowledge and co	C.aims an	1	0	1	0	0	0	0	0	0	0	0
Learning Targets	K&U	3	show an understanding of the app	C.aims an	1	0	0	0	0	0	0	0	0	0	0
Learning Targets	K&U	4	develop an understanding of curre	C.aims an	1	0	0	0	0	0	0	0	0	0	0
Learning Targets	S&P	5	make careful observations, ask rel	C.scientifi	0	0	1	0	0	0	0	0	0	0	0

To analyze the questions in the summative assessments, each question was entered in the Excel file, and each question was considered as one segment. Three types of codes were assigned to each benchmark: (1) NOS categories in the FRA framework in Table 1, (2) the skills that students use to demonstrate their NOS understanding and (3) the context in which the assessment of NOS is embedded. Two networks for the biology summative assessments were created: the first visualizes the connections among NOS categories in the FRA framework; the second visualizes the connections among NOS categories, skills and the context of assessment. The first network can be aligned and compared with the network in the curriculum document, so that the similarities and differences in the inclusion of NOS categories between curriculum and summative assessments can be examined. The second network can be examined on its own since this shows how different contexts and skills of assessment are linked to the NOS categories in the summative assessment items.

Table 2. Benchmarks in Hong Kong biology curriculum (Council & Authority, 2015)

Learning Targets

Knowledge and Understanding (K&U)

1. acquire knowledge and develop an understanding of biological principles, concepts, terms and facts;
2. apply biological knowledge and concepts to familiar and unfamiliar situations;
3. show an understanding of the application and uses of biological knowledge in daily life;
4. develop an understanding of current issues and developments in biology.

Skills and Processes (S&P)

1. make careful observations, ask relevant questions, identify problems and formulate hypotheses for investigations;
2. recognize the importance of evidence in supporting, modifying or refuting proposed scientific theories;
3. develop the ability to think scientifically and creatively;
4. acquire an analytical mind to critically evaluate biology-related issues;
5. identify the pros and cons of the application of biological knowledge for informed decision-making;
6. plan and conduct scientific investigations individually or collaboratively with appropriate instruments and methods, collect quantitative and qualitative information with accuracy, analyse data and draw conclusions for problem-solving;
7. use information technology to process and present scientific information; and
8. communicate ideas and views effectively with others, using the language of science.

Values and Attitudes (V&A)

1. show an interest in the study of biology, appreciate the wonders and complexity of Nature, show respect for all living things and the environment;
2. recognise their responsibility for conserving, protecting and maintaining the quality of the environment;
3. develop positive values and attitudes towards adopting a healthy lifestyle;
4. be aware of the dynamic nature of biological knowledge and appreciate the role of science and technology in understanding the living world; and
5. be aware of the application of biological knowledge in society and its social, ethical, economic and environmental implications.

Curriculum Emphasis

Scientific Inquiry (SI)

1. make careful observations, ask relevant questions, identify problems and formulate hypotheses for investigations;
2. plan, conduct and write reports on scientific investigations;
3. select and design appropriate methods of investigations for specific purposes;
4. use appropriate instruments and apply proper techniques for carrying out practical work;
5. identify and explain the importance of control variables in scientific investigations;
6. explain why sample size, random sampling, replicates and repeat procedures are important in scientific investigations;
7. classify, collate and display both first and second hand data;
8. use diagrams, graphs, flow charts and physical models as visual representations of phenomena and relationships arising from the data;
9. analyse and draw conclusions from data;
10. understand that the process of scientific investigations includes analysing evidence and providing explanations based upon scientific theories and concepts; and
11. formulate and revise scientific explanations and models using logic and evidence.

Science–Technology–Society–Environment Connections (STSEC)

1. develop sensitivity and responsibility in striking a balance between the needs of humans and a sustainable environment;
2. appreciate the role of science and technology in understanding the living world;
3. be aware of the application of biological knowledge in society and its social, ethical, economic and environmental implications;
4. analyse ways in which scientific and technological advancement have influenced our lives, society and the environment;
5. understand how biological knowledge is used in technological applications;
6. explain how scientific knowledge may lead to the development of new technologies and how new technologies may lead to scientific discovery;
7. be aware that societal needs have led to technological advances; and understand how science has been influenced by societies.

Nature and History of Biology (NHB)

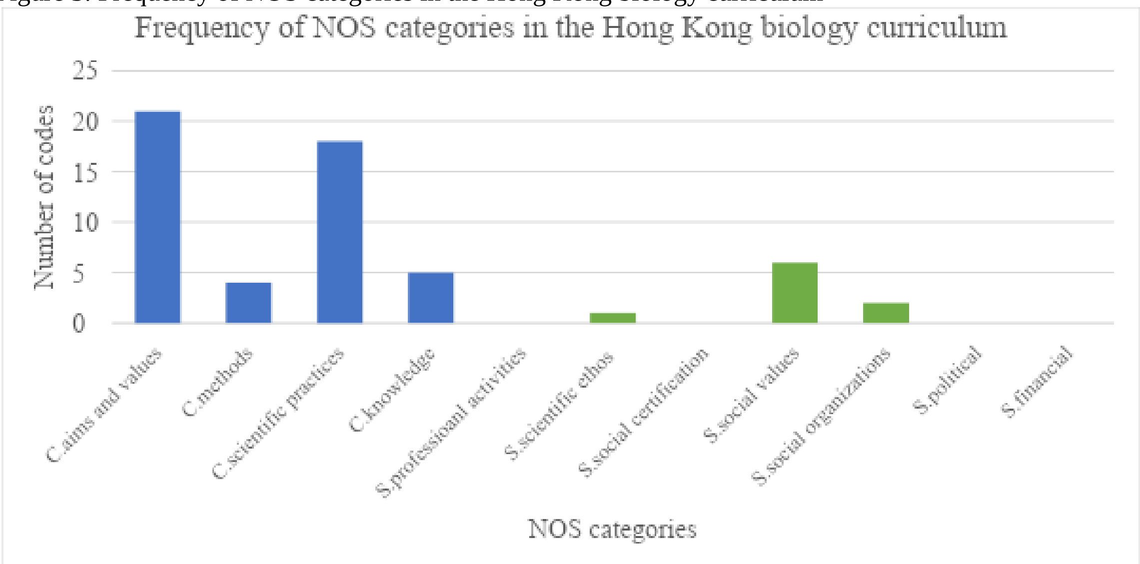
1. be aware of the dynamic nature of biological knowledge and understand that science is a human endeavour;
2. recognise the contributions of various people to understanding and applying biology;
3. be aware that biological knowledge and theories are developed through observations, hypotheses, experimentations and analyses; and
4. understand the nature and limitations of scientific activity.

4 Results

RQ1. What NOS categories are represented in the Hong Kong biology curriculum?

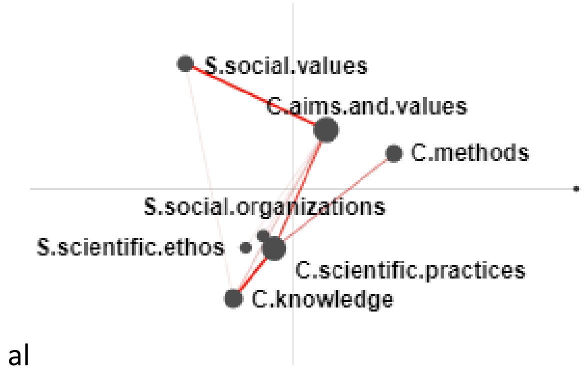
The NOS-focused benchmarks focused more on the cognitive-epistemic rather than the social-institutional system. Figure 3 shows the distribution of the number of NOS categories in the Hong Kong curriculum, while Figure 4 shows the connection among NOS categories in an epistemic network. The prefix "C" refers to the cognitive-epistemic system while the prefix "S" refers to the social-institutional system. A total of 48 codes (84%) falls into the cognitive-epistemic system, while a total of 9 codes (16%) falls into the social-institutional system. Within the cognitive-epistemic system, aims and values (21 out of 48) and scientific practices (18 out of 48) have a higher proportion compared to other categories such as methods (4 out of 48) and knowledge (5 out of 48). Within the social-institutional system, professional activities, social certification, political power and structures and financial systems are not considered in these benchmarks. Only scientific ethos (1 out of 48), social values (6 out of 48) and social organizations (2 out of 48) are considered in the curriculum. This result is similar to that of Yeh et al. (2019), who report that the consideration of the social-institutional system is far less prevalent than that of the cognitive-epistemic system.

Figure 3. Frequency of NOS categories in the Hong Kong biology curriculum



The connections among codes in each benchmark were also examined and visualized in Figure 4. A thicker line indicates a frequent connection while a thinner line indicates a less frequent connection. The most frequent connections occur between aims and values and social values and between scientific practices and knowledge. More prevalent connections are those between aims and values and scientific practices, as well as those between scientific methods and practices. Rare connections meanwhile are those between aims and values and social organizations as well as those between aims and values and scientific ethos. However, within the cognitive-epistemic system, methods are less connected to other categories. More significantly, although scientific ethos, social values and social organizations belong to the same system in FRA, they are less connected to each other.

Figure 4. ENA analysis of NOS categories in the Hong Kong biology curriculum (only categories with connections are shown)

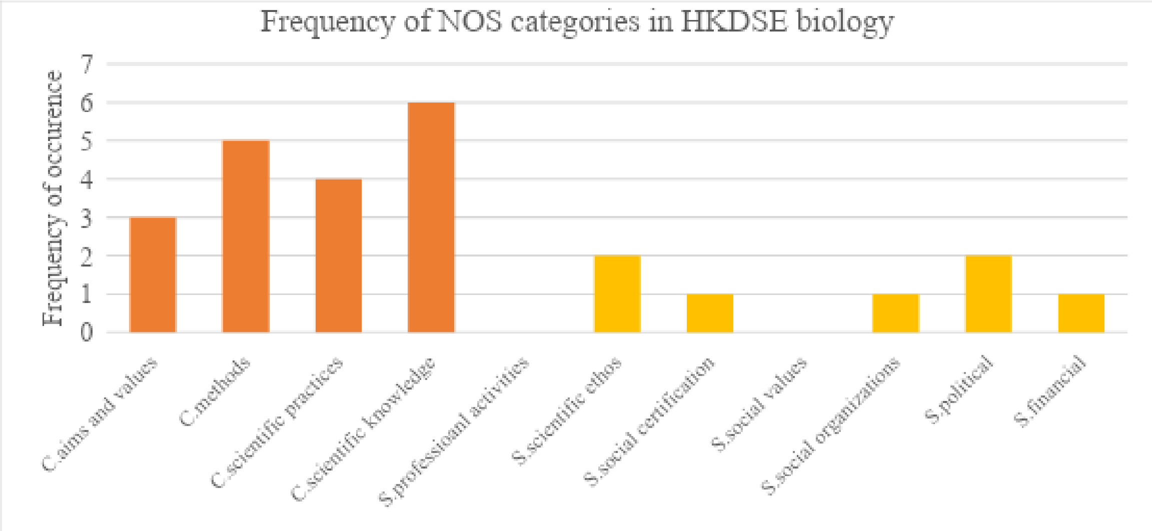


RQ2. Which elements of NOS are selected and how are NOS categories examined in the Hong Kong biology high-stakes assessments? Are these NOS categories different from those represented in the Hong Kong biology curriculum?

A total of 11 questions explicitly assess students' NOS understanding in the past examination papers (from 2012 to 2018). The maximum score of the biology paper is 120, while the number of scores allocated to the assessment of students' NOS understanding ranges from 1 to 4. Such questions are usually embedded in a long conventional question examining students' content knowledge, NOS understanding and inquiry skills.

The biology high-stakes assessments in Hong Kong focus more on the cognitive-epistemic rather than the social-institutional system. Figure 5 shows the distribution of NOS categories in each question. 18 out of 25 codes (72%) are applied to the cognitive-epistemic system, while 7 out of 25 codes (28%) are applied to the social-institutional system. The assessment items cover aims and values (3 out of 25), methods (5 out of 25), scientific practices (4 out of 25) and scientific knowledge (6 out of 25). However, within the social-institutional system, all aspects have been assessed except for social values. The findings in the high-stakes examinations contrast with those of the curriculum in three ways: (1) the assessment items cover social values but these are the most frequent among all categories in the social-institutional system; (2) the assessment items cover the categories of social certification, political power structures and financial systems, but these aspects are not presented in the curriculum; (3) the NOS categories within the cognitive-epistemic system are reasonably evenly assessed in the biology high-stakes examinations, but not in the biology curriculum. In light of these, the inclusion of NOS categories in the curriculum is inconsistent with those represented in high-stakes examinations.

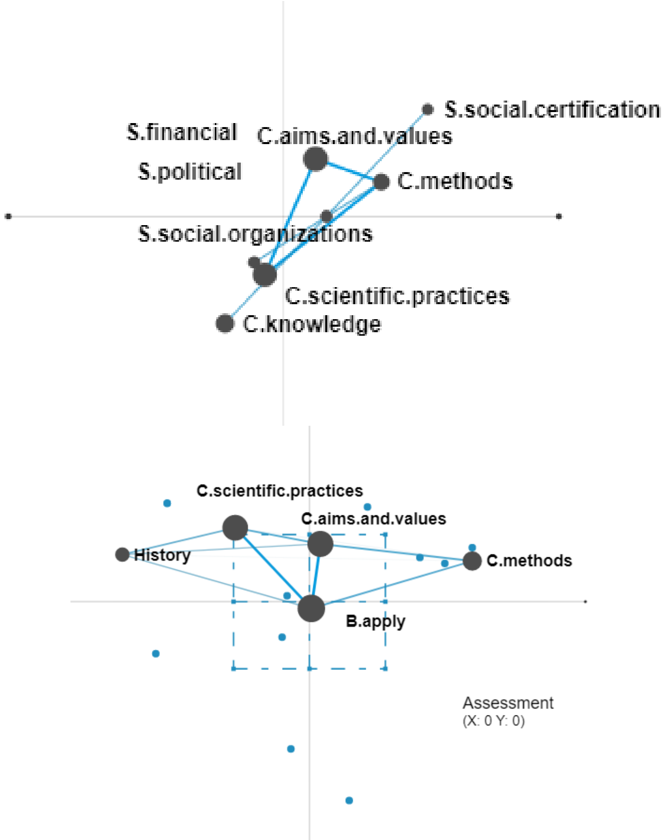
Figure 5. Frequency of NOS categories in the HKDSE biology



The connections among codes in Hong Kong biology high-stakes examinations are examined and visualized in the epistemic network in Figure 6A. Frequent connections occur between scientific practices and scientific methods, between aims and values and scientific methods, and between aims and values and scientific practices. These connections are characterized by those darkest lines in Figure 6A. There are some connections between social organizations and scientific methods, as well as between knowledge and social certification. The appearance of political power and financial systems in the epistemic network without any connection line indicates a connection between these two categories with others too weak to be visualized. Moreover, no frequent connection is evident among NOS categories within the social-institutional system.

The epistemic networks of the curriculum document and high-stakes assessments can be compared by aligning Figure 4 with Figure 6A. Two similarities between two networks are evident: (1) the cognitive-epistemic system forming the main stem of both networks; (2) the rarity of connections between categories in the social-institutional system. Nevertheless, the epistemic network of the high-stakes assessments shows more connections between NOS categories in the social-institutional system and NOS categories in the cognitive-epistemic system than that of the curriculum document.

Figure 6. (A) ENA analysis of NOS categories in the HKDSE biology (only categories with connections are shown); (B) ENA analysis of NOS categories, skills and context in the HKDSE biology (only frequent connections are shown)



Apart from NOS categories, the context and the skills gauged in the assessment items were further explored. While 81% of the questions (9 out of 11) requires students to apply their NOS understanding in new contexts, only 19% of the questions (2 out of 11) requires students to analyze and link their NOS understanding in order to explain a situation. The examination board has apparently avoided including low-order questions that involve remembering and comprehending NOS. This aligns with Allchin's (2011) notion that assessments of NOS understanding seek for higher-order skills. On the other hand, the assessment contains no question related to evaluating NOS understanding. To move to a higher order of skills of utilizing NOS understanding, the examination board may consider asking questions in relation to evaluating NOS.

Regarding the context of assessing NOS, 45% of the assessment items (5 out of 11) are embedded in the context of history of science and inquiry. In this context, students are first introduced to a historical story of scientific discovery, and required to act like a scientist to come up with hypotheses, find out variables and draw conclusions based on the information in the question. For example, in 2017 HKDSE (HKDSE, 2017), one question tries to situate students within the story of Alfred Sturtevant, who hypothesized that the ability to roll one's tongue is determined by a single gene. Students are asked to deduce whether tongue rolling is the dominant phenotype. Subsequently, there was emerging evidence in the class on the factors affecting tongue-rolling traits. Students are asked to reflect on the epistemology of science, i.e. that science is a process of ongoing inquiries. 36% of the assessment items (4 out of 11) are embedded in the context of mere history of science. Only 18% of the assessment items (2 out of 11) are embedded in the context of contemporary socio-scientific issues. Though socio-scientific issues can provide a rich repertoire for shaping students' NOS understanding (Schalk, 2012), the relevant authority does not ground assessment questions in socio-scientific matters.

The ENA analysis of NOS categories, skills and contexts of assessment is shown in Figure 6B. Given their numerous interconnections, only those frequently occurring are shown in the figure. As the figure indicates, the NOS categories, scientific practices and aims and values are often examined in the context of history and philosophy of science. Moreover, the high-stakes assessments often ask students to apply their understandings of aims and values, methods and scientific practices to answering the questions in explicit assessments of NOS. The frequent connections in ENA are restricted to specific NOS categories (aims and values, methods and scientific practices).

5 Discussion

This study explores the representation of NOS in two important types of documents – the curriculum and the high-stakes assessments in Hong Kong. ENA is adopted to analyze and visualize the dynamic connections among NOS categories in the Hong Kong biology curriculum and seven-year high-stakes examinations as well as those among NOS categories, context and skills of assessments in the high-stakes examinations. Two similarities of the two epistemic networks are observed: (1) a greater emphasis on the cognitive-epistemic system rather than the social-institutional system; (2) the scarcity of connections between categories in the social-institutional system. However, the high-stakes assessments differ from the curriculum in terms of having more connections between the cognitive-epistemic system and the social-institutional system. Moreover, assessment items in Hong Kong biology examinations involve a limited range of contexts and skills.

The empirical data of this paper has shown that the use of FRA as a theoretical framework and ENA as a data analysis tool could potentially identify frequently interconnected NOS categories as well as those which are rare. In particular, the intra-connections among categories in the social-institutional system and the inter-connections between categories in the cognitive-epistemic system and the social-institutional system in curriculum and assessments can be visualized using epistemic networks. This method allows us to reconsider whether NOS instruction should focus on students' understandings of a list of declarative statements or coherent and reflexive understandings of the cognitive and sociological aspects of science (Allchin, 2011; Matthews, 2012; Smith & Scharmann, 1999; Wong & Hodson, 2009). More importantly, this work also provides an innovative way to analyze the portrayal of NOS in curriculum materials, which differs significantly from the past studies (Abd-El-Khalick et al., 2008; Kaya & Erduran, 2016).

A key finding of this study is that NOS categories in relation to the social-institutional system are downplayed in both the Hong Kong curriculum and assessments. Although previous studies have revealed a downplaying of the socio-institutional system, these studies did not reveal how weakly these categories are connected to each other (see examples from Yeh et al., 2019). As Driver et al. (1996) and Wong and Hodson (2009) argue, learning NOS can enable students to evaluate socioscientific issues and make sense of the contemporary science phenomenon. This is because the way that students conceptualize NOS affects how they respond to socio-scientific issues (Karisan & Zeidler, 2017; Sadler, Chambers, & Zeidler, 2007; Zeidler, Sadler, Simmons, & Howes, 2005). However, the categories of professional activities, social certification and dissemination and political power structures and financial systems are absent in the curriculum document, while the categories of professional activities and social values are absent in the high-stakes examinations. One of the features of the FRA framework is the connections among "social organizations and interactions", "political power structures" and "financial systems", which are crucial to students' understanding of how scientific enterprises are tied to social and cultural forces (Erduran & Dagher, 2014). Nevertheless, the results of this study highlight an insufficient articulation of and interconnection among these categories. The policy makers and examiners should consider including these NOS categories in curriculum and assessment (Wong & Hodson, 2009), so that these categories are not lessened in classroom instruction.

More connections among the NOS categories within the cognitive-epistemic system in both the Hong Kong biology curriculum and its high-stakes assessments are also observed. Seldom do these categories extend to the broader social contexts, that is, the social-institutional system. The authentic works of scientists cannot be known by students if the interaction between the work of science and society is neglected in both the curriculum and the high-stakes assessments (Wong & Hodson, 2009). For example, the success of scientists does not only depend on the success of the experiments, but is also affected by the availability of funding and government's funding allocation to particular scientific disciplines (Erduran & Dagher, 2014). The "consensus" list from Lederman et al. (2002) only covered two aspects of how society and science are intertwined, namely, social-cultural embeddedness and social dimension of science. Their "consensus" list provides a limited account of how society affects the work of science. Students' understanding of NOS should be extended to a broader social context (Allchin, 2017) thus empowering them to become responsible civil citizens (Wong & Hodson, 2009).

Assessment items in Hong Kong biology examinations involve a limited range of contexts and skills. Teachers may use these assessment items to decide what skills and contexts are relevant teaching and assessment in their classrooms (Jonsson & Leden, 2019; Wan & Wong, 2017). Allchin (2011) called for the inclusion of evaluating NOS in assessment items. He also argued that assessments should be embedded in *authentic* contexts, such as excerpts from newspapers and magazines. Clearly, high-stakes examinations cannot include items requiring students to evaluate NOS understanding, as this may create difficulties in setting up a marking scheme that can consistently differentiate students into distinct levels. However, it is suggested that future assessment items should embed NOS questions in socio-scientific issues rather than mere history of science and inquiry. It has been long argued that classroom teaching and assessment is shaped by the format of high-stakes assessments. For example, Erduran, Cullinane, et al. (2019) claimed that the "cookbook practical" (students following experimental procedures in textbooks without considering the ideas behind the experiments) may possibly be due to the impact of assessment questions in public examinations. Similarly, to avoid "cookbook NOS", students should use a broader range of skills to articulate NOS ideas in a wider range of contexts during assessments. As seen in the epistemic network of the high-stakes assessments, the limited skills and contexts are confined to the cognitive-epistemic system and are less connected to the social-institutional system. Assessment items should not be limited to how an NOS idea is demonstrated in history of scientific discovery. The examination board can consider setting up questions for students to justify the importance of NOS ideas to scientific discovery in a broader social context (Allchin, 2017).

This work aims to initiate a discussion on *what* and *how* NOS should be assessed in national summative assessments. It also offers a suggestion that assessments of NOS should allow students to extend their understandings from the epistemic aspects of science to the social aspects of science. The reconceptualized FRA framework is adopted in this study because it aligns with the author's view towards NOS and the aims of this work. Readers should note that this study does not attempt to make assertions on which perspectives of NOS should be adopted in science classrooms. There are other frameworks of NOS that maybe useful to explore the inclusion of NOS in the curriculum and the high-stakes assessments. Moreover, this study uses categories as the units of analysis because it allows a clear and direct comparison between the network in the curriculum and that in the high-stakes assessments. This also provides readers an idea of how NOS is coherently addressed in the curriculum and the high-stakes assessments. A fine-grained analysis approach might not align with the purposes of this study because the networks created by this approach contain scattered information which are difficult for science educators to compare and interpret. Finally, it should be noted that the finding of this study is limited to the context of Hong Kong. Future studies can be carried out to investigate the ways in which different curricula and high-stakes assessments around the world include NOS categories. Data could then be analyzed through visualizing connections among NOS categories, skills and context, as shown in this study. Moreover, science educators who are keen to extend students' epistemological understanding of science to a broader context can use FRA to explore how students' attitudes and progression of learning NOS can be affected by instruction focused on socioscientific issues.

6 Conclusion

This study uses reconceptualized FRA to explore the inclusion of NOS in curriculum and high-stakes assessments. It shows that ENA is a highly successful approach to visualizing NOS categories' interdependency. It visualizes how the *intra*-connection of NOS categories within a system as well as the *inter*-connection between the cognitive-epistemic system and the social-institutional system. The findings reveal that NOS is represented as disjointed categories, with some of the NOS categories in the social-institutional system missing. The NOS categories in the social-institutional system is disconnected with those in the cognitive-epistemic system. Apart from the content of NOS, the contexts and the skills of assessments remain limited. Science educators who are involved in designing curricula and assessments should consider carefully how NOS is included. Greater awareness on the part of curriculum and high-stakes assessment developers can result in student understandings of NOS which are more holistic, more nuanced, and extended to a far broader social context. More importantly, students' understanding of NOS can be taught and assessed in a wider range of skills and contexts, and these skills and contexts can be linked to NOS categories in both the cognitive-epistemic system and the social-institutional system. Future research efforts should be devoted to studying how curriculum and high-stakes assessments influence students' learning of the network nature of NOS. FRA offers a convincing and potential framework for this purpose.

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Dear Editor

Thank you very much for accepting my manuscript. Please note that the conclusion part has been further extended. Please see below:

This study uses reconceptualized FRA to explore the inclusion of NOS in curriculum and high-stakes assessments. It shows that ENA is a highly successful approach to visualizing NOS categories' interdependency. It visualizes how the *intra*-connection of NOS categories within a system as well as the *inter*-connection between the cognitive-epistemic system and the social-institutional system. The findings reveal that NOS is represented as disjointed categories, with some of the NOS categories in the social-institutional system missing. The NOS categories in the social-institutional system is disconnected with those in the cognitive-epistemic system. Apart from the content of NOS, the contexts and the skills of assessments remain limited. Science educators who are involved in designing curricula and assessments should consider carefully how NOS is included. Greater awareness on the part of curriculum and high-stakes assessment developers can result in student understandings of NOS which are more holistic, more nuanced, and extended to a far broader social context. More importantly, students' understanding of NOS can be taught and assessed in a wider range of skills and contexts, and these skills and contexts can be linked to NOS categories in both the cognitive-epistemic system and the social-institutional system. Future research efforts should be devoted to studying how curriculum and high-stakes assessments influence students' learning of the network nature of NOS. FRA offers a convincing and potential framework for this purpose.

Thank you very much for processing this manuscript.

Best regards
Kason Cheung