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ARTICLE

Investigating Scientists' Views of the Family Resemblance Approach to Nature of Science in Science Education

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Abstract

In this paper, we use the "Family Resemblance Approach" (FRA) as a framework to characterize how scientists view the nature of science (NOS). FRA presents NOS as a "system" that includes clusters or categories of ideas about the cognitive-epistemic and social-institutional aspects of science. For example, the cognitive-epistemic aspects include aims and values such as objectivity and scientific methods such as hypothesis testing. Social-institutional aspects refer to a range of components including social values such as honesty about evidence and institutional contexts of science such as research institutions. Characterized as such, NOS is thus a system of interacting components. The initial account of FRA was proposed by philosophers of science and subsequently adapted and extended for science education including through empirical studies. Yet, there is little understanding of the extent to which FRA coheres with scientists' own depictions about NOS. Hence, an empirical study was conducted with scientists to investigate their views about FRA as well as their views of NOS using the FRA framework. In so doing, the research sought to explore the utility of FRA from scientists' point of view. Qualitative and quantitative analysis of 17 Taiwanese scientists' responses to a set of written questions indicates that scientists are in agreement with the FRA account of NOS, and they detail all aspects in their reference to NOS, although the social-institutional aspects are underrepresented in their depiction. Implications for further studies and science education are discussed.

1 Introduction

Recent curriculum policy standards have emphasized the representation of authentic scientific practices in school science. For instance, the *Next Generation Science Standards* (NGSS) stresses the importance of including in education scientific practices as exercised by scientists themselves such as modeling and argumentation (Next Generation Science

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Standards (NGSS) 2013). It has been long argued that given that scientists are the agents of science, the narratives of the scientist can potentially inform education and enthuse students as they engage in school science (Larison, 2018). Understanding scientists' views about how science works in relation to a range of aspects of science (e.g., aims, practices, methods) can potentially help inform how students' participation in sciences can be enhanced (Allchin et al., 2014; Hodson, 2014).

Various strategies have been proposed to enact innovative curriculum standards, for example, in terms of teaching about scientific practices. Allchin et al. (2014) articulated the merits, deficits, and context of three approaches: historical cases, contemporary cases, and student inquiry activities. These authors suggested these approaches should be integrated as complementary methods and be contextualized in various scenarios. Hodson and Wong (2017) grouped various target experiences for students into three categories: (1) Learning about scientists, views from historians, philosophers, sociologists, science educators and science commentators; (2) learning from scientists, perspectives and interpretation from scientists; and (3) learning with scientists, first-hand experience of students. The authors suggested that these approaches will broaden and enrich students' understanding of nature of science (NOS) and acquisition of scientific literacy.

There is now considerable amount of research on scientists' views about NOS (e.g., González-García et al., 2019; Osborne et al., 2003; Schwartz, & Lederman, 2008; Wong & Hodson, 2009, 2010; Yucel, 2018). The line of work in science education referred to as NOS in science education has in fact been influenced by both theoretical reviews as well as empirical research on what scientists consider to be pivotal aspects of science for students to learn (e.g., Allchin et al., 2014; Kimball, 1968; Lederman et al., 2002). However, the precise definition of NOS has been debated for some time (e.g., Allchin, 2011; Irzik & Nola, 2011, 2014; Kampourakis, 2016; Matthews, 2012).

McComas and Olson (1998) analyzed eight science standards documents from different countries and concluded that statements related to NOS in these documents were identified as 50 distinct NOS concepts. They also acknowledged that no precise and completely agreed upon description exists regarding NOS though these documents reflect some agreement about what students should learn about NOS. In addition, Olson (2018) examined nine international science education standards documents and indicated that consensus was not apparent in the overt learning outcomes for students.

The "Family Resemblance Approach" (FRA) is a recent framework about NOS (Erduran & Dagher, 2014; Irzik & Nola, 2014). Unlike previous depictions of NOS, FRA presents NOS as a "system" that includes clusters or categories of ideas about science. Science in this sense is a cognitive-epistemic and social-institutional system. For example, the cognitive-epistemic aspects include aims and values such as objectivity and scientific methods such as hypothesis testing. Social-institutional aspects refer to a range of components such as social values (e.g., honesty in scientific research) and organizational contexts (e.g., research institutes where science takes place). NOS is thus a system of interacting components. The initial account of FRA was proposed by philosophers of science (Irzik & Nola, 2011) and subsequently adapted and extended for science education in a book length conceptual account (Erduran & Dagher, 2014) as well as in the context of empirical studies (Akbayrak & Kaya, 2020; Akgun & Kaya, 2020; BouJaoude et al., 2017; Cheung, 2020; Erduran et al. 2020; Erduran & Kaya, 2019; Kaya et al., 2019; Kelly & Erduran, 2019; McDonald, 2017; Park, Yang, et al., 2020; Park, Wu, et al., 2020; Park Yang, & Song, 2020; Park, Wu, et al., 2020; Petersen et al. 2020; Yeh et al., 2019).

Yet, no research has yet been conducted to investigate the extent to which FRA coheres with scientists' own depictions about NOS. Considering that FRA is a relatively new account about NOS framed from philosophers and educators' accounts, it is worthwhile to ask if its depiction of NOS is coherent with how scientists view NOS. The purpose of this paper, then, is to examine how scientists view NOS in general and from the perspective of FRA in particular with implications for science education research and curriculum policy. Understanding how scientists view NOS will have implications for the educational utility of FRA.

The paper begins with a theoretical background on how research literature in science education addressed scientists' views about NOS. Following on from this discussion, closer attention is paid to FRA to frame the empirical study with scientists presented subsequently in the paper. Although the empirical base of research on FRA in science education has been growing (e.g., Cheung, 2020; Erduran & Kaya, 2019, 2018; Erduran & Kaya, 2018; Erduran et al., 2020; McDonald, 2017; Park et al., 2020a; Park et al., 2020b), there is limited understanding of the extent to which FRA coheres with scientists' own depictions about NOS. Hence, an empirical study was conducted with scientists to investigate their views about FRA. In so doing, the researchers sought to explore the utility of FRA for characterizing NOS from scientists' point of view. The empirical study focused on 17 Taiwanese scientists from different fields of science. Qualitative and quantitative analyses of the scientists' responses to a set of written questions will be presented with implications for the educational adaptations of FRA.

2 Nature of Science and Scientists' Views

There is now a significant body of research in science education on "nature of science" (NOS) (Abd-El-Khalick, 2012; Kampourakis, 2016; Lederman et al., 2002; McComas & Olson, 1998; Osborne, 2017). Research on NOS aims to incorporate in science education aspects of science that get at what science is about and how science works (Erduran & Dagher, 2014) and has been promoted since the 1960s (e.g., Kimball, 1968). A central characterization of NOS has been what is often referred to as the "consensus view" (Abd-El-Khalick & Lederman, 2000; McComas & Olson, 1998). The most widely adopted conceptualization of NOS is based on two elements: aspects of the nature of scientific knowledge (NOSK) and aspects of scientific inquiry (SI) (Kampourakis, 2016; Lederman & Lederman, 2012). NOSK include seven aspects: (1) observation and inference are different; (2) scientific laws and theories are distinct forms of knowledge; (3) scientific knowledge is empirical, as it is based on and/or derived from observations of the natural world; (4) scientific knowledge involves human imagination and creativity; (5) scientific knowledge is subjective; (6) scientific knowledge is influenced by the cultural contexts in which it is developed; and (7) scientific knowledge is never absolute or certain but tentative and subject to change.

Scientific inquiry refers to the following eight aspects: (1) scientific investigations all begin with a question, but do not necessarily test a hypothesis; (2) there is no single set and sequence of steps followed in all scientific investigations (i.e., no single scientific method); (3) inquiry procedures are guided by the question asked; (4) all scientists performing the same procedures might not get the same results; (5) inquiry procedures can influence the results; (6) research conclusions must be consistent with the data collected; (7) scientific data are not the same as scientific evidence; and (8) explanations are developed from a combination of collected data and what is already known.

In a recent Delphi survey (González-García et al., 2019), 12 NOS themes were proposed by 31 Spanish experts from different science-related fields: (1) science versus other human activities for generating knowledge, (2) rationality, (3) the languages of science, (4) nature of scientific knowledge, (5) the methods of science, (6) the role of problem definition and problem solving in science, (7) observation, (8) critical attitude, (9) curiosity, (10) scientific work, (11) relationship between science–technology–society and the environment, and (12) the role and function of technology and of people's relationship to it. However, only the "critical attitude" theme was considered a stable consensus and a key aspect of scientific competence for citizenship. Therefore, the authors indicated that it is difficult to define NOS. On the other hand, Wong and Hodson (2009, 2010) focused on scientists, especially who work at "cutting edge" of science. Based on the diverse responds of thirteen scientists, they questioned the consensus arguments of NOS and stressed that their views are context-specific.

Previously, Schwartz and Lederman (2008) examined the views of different groups from science disciplines, and they found that scientists' NOS views are not necessarily related to science discipline context but embedded within individual contexts and experiences. More recently, Bayir et al. (2014) compared the views of scientists who were experts in social sciences and those who were experts in natural sciences, and the comparison showed that their views were not substantially different. However, the results of these studies revealed that scientists are classified as holding blended views in several aspects rather than consistent and sophisticated/informed views (Elby & Hammer, 2001). Bayir et al. (2014) indicated that if scientists do not reflect on their scientific practices in a philosophical sense, their views about NOS may raise questions about the authenticity of NOS accounts. After investigating the contextual nature of scientist' view, Sandoval and Redman (2015) concluded that the contradiction was resulted from the conflation of ontology and epistemology. Yucel (2018) used the framework of Bhaskar's critical realism to analyze academic scientists' ontological and epistemological views, the results indicating that scientists hold different commitments regarding both dimensions of science.

Tenets about NOS have thus been reported in both theoretical and empirical studies about NOS and about scientists' views (e.g., Kimball, 1968; Osborne et al., 2003; Yucel, 2018). For example, Kimball's work in the 1960s focused on theoretical work from philosophy of science and generated a set of statements such as "Tentativeness and uncertainty mark all of science. Nothing is ever completely proven in science, and recognition of this fact is a guiding consideration of the discipline." (Kimball, 1968, pp. 111–112). More recently, Osborne et al. (2003) explored NOS views by investigating not only scientists but also science educators, historians, philosophers, and sociologists of science, science communicators, and science teachers. After a three-stage Delphi survey, nine themes were determined with a high level of agreement, and they included themes such as the scientific method and creativity. Across several decades, then, a set of statements about NOS have been noted by different researchers (e.g., Cotham & Smith, 1981; Showalter, 1974).

Considering some of the range of accounts about NOS as well as scientists' views about NOS, it is worthwhile to investigate how a relatively recent account of NOS may be interpreted by scientists. The Family Resemblance Approach (FRA) to NOS is a framework that has been proposed by philosophers of science (Irzik & Nola, 2011, 2014) and advocated by science education researchers (Erduran & Dagher, 2014) as a useful framework to characterize how science works. As of yet, there are no studies involving scientists reflecting on FRA as a plausible account of NOS. Before visiting this question empirically through a study conducted with practicing scientists, we will review the FRA framework in more detail and illustrate its existing applications in science education.

3 Family Resemblance Approach to Nature of Science

The contributions of the FRA in science education have been documented in a recent review (Erduran et al., 2019). For example, FRA has been applied to teacher education (Kaya et al., 2019), undergraduate teaching and learning (Akgun & Kaya, 2020; Petersen et al., 2020), curriculum analysis (Cheung, 2020; Kaya & Erduran, 2016; Yeh et al., 2019), textbook analysis (McDonald, 2017; Park, Wu, et al., 2020; Park, Yang, et al., 2020), and STEM education (Couso & Simmaro, 2020; Park et al., 2020b). Erduran, Kaya, and Avraamidou (2020) investigated how the FRA framework could be linked to broader curricular goals related to social justice, and the utility of FRA in the enculturation of university students in scientific cultures has been explored (Mohan & Kelly, 2020).

Irzik and Nola's (2011) account was inspired by Wittgenstein's idea of "family resemblances." FRA considers the various branches of science as a "family" with some characteristics that are similar as well as specific to each member. At the heart of FRA framework is the recognition that, when one chooses any two disciplines under the umbrella of "science," they will share certain characteristics and they will also be dissimilar to one another with respect to other aspects (Irzik & Nola, 2014). For example, astronomers and particle physicists commonly construct hypotheses, collect empirical data, and interpret the meaning of the data, but only the latter conduct laboratory experiments to test their hypotheses (Irzik & Nola, 2014). On the other hand, when physics is compared to medical science, while both have common aspects (e.g., collecting data, making inferences, and predictions), the latter features randomized controlled trial as a powerful method to draw conclusions about causal relationships, which particle physicists rarely do (Irzik & Nola, 2014). This means that there is no clear set of necessary and sufficient conditions that defines NOS. Rather, there are arrays of "resemblances" between the sub-areas of science that help characterize them all as "science."

Erduran and Dagher's (2014) version of the FRA includes 11 categories that are subsumed in two systems as represented by the first two columns in Table 1. The third column contains the keywords used by Kaya and Erduran (2016) to illustrate some of the main ideas associated with each category of FRA when they applied the FRA framework to curriculum analysis. The first set of categories is related to *science as cognitive-epistemic system* and consists of four categories: aims and values, methods and methodological rules, scientific knowledge, and scientific practices. The second set of categories refers to *science as a social-institutional system* and consists of other seven categories: professional activities, scientific ethos, social certification and dissemination of scientific knowledge, social values, social organizations and interactions, political power structures, and financial systems.

The FRA framework accounts for both domain-general and domain-specific features of science, and it provides sets of ideas that can be discussed separately as well as collectively in relation to one another, as part of a system. Erduran and Dagher's (2014) account of FRA introduced a visual representation (see Fig. 1) where the relationships between the different categories can be represented. The FRA categories are viewed as being interdependent and co-influencing one another. The overall framework is thus considered in a holistic fashion where each component is interlinked to others. For example, the types of questions that may be asked in science that will drive the epistemic aims and values of science may be mediated by financial systems, where funders may specify which line of research should be pursued in a funding call.

Although the relevance of the FRA framework for science education has been evidenced in numerous recent studies including those focusing on teacher education

Table 1 Definitions of FRA categories and indicative keywords

Category	Definition	Indicative keywords
Aims and values	Aims and values refer to a set of aims in the sense that the products of scientific activity are desired to fulfill them	Aim, value, goal, accuracy, objectivity
Methods	Methods and methodological rules refer to the variety of systematic approaches and the rules that scientists use to ensure that they yield reliable knowledge	Method, scientific method, inquiry, process, hypothesis, manipulation of variables
Practices	Scientific practices refer to a diverse set of practices that are underpinned by cognitive, epistemic, and social-institutional activities	Observation, experimentation, data, explanation, model, argumentation, classification, prediction
Knowledge	Scientific knowledge refers to the “end-products” of scientific activity that culminate in “laws, theories, models, and the collection of observational reports and experimental data”	Knowledge, scientific knowledge, formulation of knowledge, theory, law, model
Social certification and dissemination	Social certification and dissemination of scientific knowledge refers to the peer review process, which tends to work as “social quality control over and above the epistemic control mechanisms that include testing, evidential relations, and methodological consideration”	Peer review, validate, evaluate, certification, dissemination, collaboration
Scientific ethos	Scientific ethos refers to the set of norms scientists follow in their own work and their interactions with one another	Scientific norms, ethics, bias, being skeptical, caution against bias
Social values	Social values of science refer to values such as “respect for the environment and social utility, which is broadly understood to refer to improving people’s health and quality of life as well as to contributing to economic development”	Culture, cultural, social values, society, beliefs, freedom, respect
Professional activities	Professional activities refer to activities that scientists perform in order to communicate their research, such as attending professional meetings to present their findings, writing manuscripts for publications, and developing grant proposals to obtain funding	Conference, article, presentation, writing, publishing, publication
Social organizations and interactions	The broader features of political power structures, financial systems, and social organizations and interactions are referred to as broad because finance, politics and institutions are integral components of the larger society in which science, like other organized human activity, is being practiced	University, research center, institution, organization
Financial systems		Financial, funding, finance, economy, economical, budget
Political power structures		Political power, research team, team leader, team members, researcher, gender, ethnicity, race, nationality

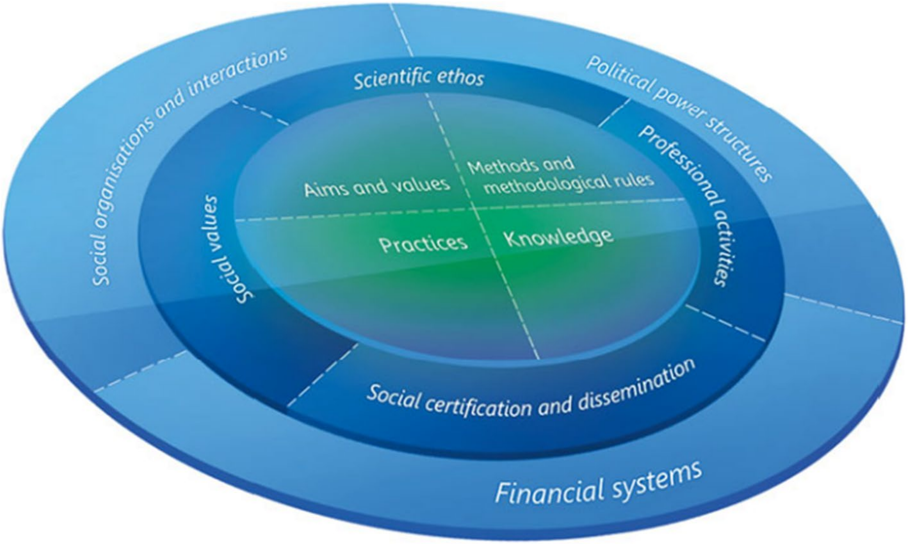

Fig. 1 FRA framework (Erduran & Dagher, 2014, p.28)

(Kaya et al. 2019), undergraduate teaching (Petersen et al., 2020), curriculum analysis (Cheung, 2020; Kaya & Erduran, 2016; Yeh et al., 2019), textbook analysis (BouJaoude et al., 2017; McDonald, 2017; Park, Wu, et al., 2020; Park, Yang, et al., 2020), and STEM education (Couso & Simmaro, 2020), scientists' views of FRA have not been investigated. Considering FRA is a relatively new account about NOS, it is worthwhile to ask if its depiction of NOS is coherent with how scientists view NOS. Furthermore, a significant proportion of the scientists who were part of the samples in the research studies on scientists' views about NOS (e.g., Kimball, 1968; Osborne et al., 2003) have been from western countries. The purpose of this paper, then, is to examine how scientists view NOS in general and from the perspective of FRA in particular. The scientists themselves are drawn from a sample of scientists from Taiwan working in a range of sub-disciplines of science such as neuroscience, seismology, laser physics, nanoscience, and chemical oceanography.

4 Methodology

4.1 Research Question

The empirical study was guided by the following research question: *How do Taiwanese scientists view nature of science (NOS), particularly NOS as characterized by the Family Resemblance Approach (FRA)?*

4.2 Sample

The sample consists of 17 Taiwanese scientists who were keen on science communication and outreach. The emphasis on science communication and outreach was important to ensure recruitment and engagement in a science education research project. A search by the first author native to Taiwan resulted in a list of Taiwanese university professors who (a) gave a public lecture or (b) conducted a video recorded presentation for a broad audience in the past three years. Invitations were sent to more than one hundred professors from diverse sub-disciplines of science with experiences in science communication and outreach. Seventeen professors (1 female and 16 males) from different Taiwanese institutions volunteered to take part and expressed strong concern about science education. Their broad research fields were as follows: biology ($n=5$), chemistry ($n=5$), earth science ($n=4$), and physics ($n=3$), and each participant was labeled B, C, E, and P (i.e., B is for biology, C for chemistry, and so on), according to their sub-disciplines with a number to keep their anonymity. Their ages ranged from 41 to 65, and the majority (n=16) was male with only 1 female scientist in the overall sample. Details about the participants are summarized in Table 2. All participants had rich outreach experiences such as giving public lectures, recording science videos, and writing public scientific articles aimed at public understanding of science.

4.3 Data Collection

The scientists' views of NOS were elicited through five open-ended questions that required written responses (Table 3), with the goal of obtaining as much detail as possible. The first item was about their views about the FRA framework and their own definition of science. Brief definitions of 11 categories of the FRA (Table 1) as well as a picture of the FRA wheel (Fig. 2) were provided to the participants. The participants were not provided with

Table 2 Details of the participating scientists

Code	Gender	Age	Position	Research field
B1	Male	42	Associate professor	Stem cell biology, cancer biology
B2	Male	49	Professor	Neuroscience
B3	Male	53	Professor	Marine biology, ecology
B4	Male	60	Professor	Population genetics, evolutionary biology
B5	Male	60	Professor	Entomology
C1	Male	41	Professor	Nanoscience, nanotechnology education, analytical chemistry
C2	Male	43	Associate professor	Analytical chemistry, material science, green energy
C3	Male	50	Professor	Material chemistry
C4	Male	51	Professor	Food chemistry
C5	Male	65	Professor	Analytical chemistry, green chemistry
E1	Female	46	Professor	Structural geology, geochronology
E2	Male	43	Professor	Hydrology, physical geography
E3	Male	49	Professor	Chemical oceanography
E4	Male	54	Research scientist/ adjunct associate professor	Seismology
P1	Male	46	Professor	Condensed matter experiments, surface science, nanotechnology
P2	Male	60	Professor	General relativity, nonlinear dynamics, atmospheric electricity
P3	Male	64	Associate professor	Laser physics

Table 3 Questions for eliciting scientists' views of NOS

1.Do you agree with the depiction of FRA? If yes, please explain why? If not, how do you define science?

2.What characteristics does science have relative to these various FRA categories? What are the essential characteristics of your own inquiry practices that are important to be communicated/conveyed in your popular science education activities for people to understand? Please interpret your perspectives on (a) the characteristics and (b) their importance from at least six FRA categories

3.In your popular science education activities, what are your pedagogical approaches for communicating/conveying these essential characteristics that you mentioned in question 2? How do the approaches influence participants' understanding? Please describe your implementation in terms of (a) the pedagogical approaches and (b) the learning context

4.In your opinion, what are the essential characteristics of scientific practices that are important to be communicated/conveyed in secondary science curriculum for secondary students to understand? Please interpret your perspectives on (a) the characteristics and (b) their importance from at least six FRA categories

5.How could these essential characteristics that you mentioned in question 4 be communicated/conveyed in the secondary science curriculum so that students could understand the essential characteristics of science? Please interpret your suggestions for (a) the pedagogical approaches and (b) suitable learning contexts

any in-depth consideration of the "family resemblance" idea from a philosophical point of view. We were conscious that a deep philosophical discussion may not be fruitful with the scientists given we had a pragmatic goal as educators to simply verify how the FRA categories are perceived by the scientists. A statement about how science disciplines may be similar and different relative to the FRA categories was provided briefly in the overall description of the framework. The fact that the FRA framework was provided to all scientists at the onset of the set of questions ensured that scientists were responding about NOS on an equal footing, being exposed to a comprehensive set of categories about different aspects of NOS. Any differences in the emphases on particular FRA categories could therefore be attributed to their individual views and preferences in the discussion.

Apart from eliciting scientists' views about the utility of the FRA framework, we were also interested in their views of how they perceive the role of teaching and learning of NOS for citizenship and secondary education. Therefore, two questions were about their views about

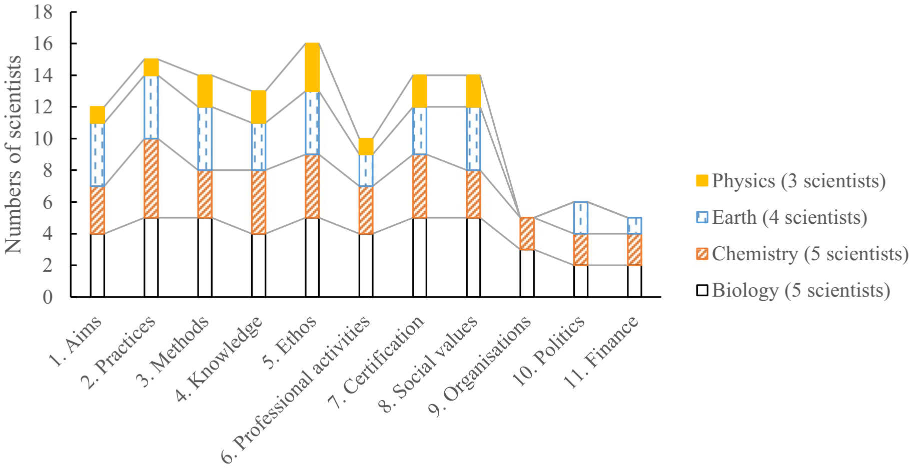

Fig. 2 FRA categories referenced by scientists by discipline

secondary school science education. In this paper, we focus on scientists' responses with regard to their views about NOS derived from their answers to questions 1, 2 and 4. Their suggestions for pedagogical approaches will be reported in a future article.

4.4 Data Analysis

The analysis was guided by the theoretical categories of FRA as defined by Erduran and Dagher (2014). The process involved comparing the theoretical definitions and the empirical statements from scientists and how they might relate to each other (Strauss & Corbin, 1998). One major challenge in analyzing text is deciding the unit of analysis, or unitization (Campbell et al., 2013). The written responses of the 17 participants were analyzed in two steps. First, the responses were categorized into the 11 FRA categories. Based on the descriptions of each FRA, the entire content of the scientists' written responses was reviewed by two coders independently to identify indicative statements by using the definition of each category and a set of keywords to identify indicative statements in scientists' responses (Erduran & Dagher, 2014; Kaya & Erduran, 2016). For example, the statement "It is the process of testing competing hypotheses which always leads science toward the truth, although the truth may not yet be attained" given the emphasis on truth, the statement was classified as an example of "aims and values." We began the analysis by running an initial search in scientists' written texts based on the indicative keywords included in Table 1.

Through this process, statements that describe the content of the FRA categories were identified. Since the keywords may not occur in the statements and the sense of each FRA category could be implicit, a second step was conducted. This step was necessary because there often were statements relevant for each FRA category but without explicit words such as "aim," "value," or "practice." The search results were then reviewed by the two researchers to ensure that the keywords actually referred to the FRA category and were not being used for other meanings (e.g., using "aim" to refer to what the scientists target in their teaching, not necessary about aims of the scientific enterprise).

Using a constant comparative method, all responses were reviewed by the first author. The second author reviewed the statements of the themes and the related responses. The authors recognized that the nuance around the interpretation of the statements to fit them in a particular category was often challenging as there were occasions when multiple categories might have been implied. The coding was thus guided by the local context of meaning in the text. A more elaborate analysis in the future could potentially inter-relate the categories where there may be overlapping themes. For the purposes of this study, capturing how Taiwanese scientists view FRA broadly speaking was a priority, and some of the nuances around statements were not particularly relevant for the purposes of the current study. The particular emphases in scientists' responses can potentially be studied in future studies.

The researchers' interpretations were sent to the scientists for commenting on the coding of their own responses with the FRA categories. The purpose of this final step was to ensure that the researchers' characterization of the scientists' responses was in agreement with how the scientists themselves viewed them. If the participants had any disagreements with the researchers' characterization, they could state so. In summary, the researchers' and scientists' interpretations were crossed checked using Intercoder Agreement (ICA) processes (Guest et al. 2012). ICA was greater than 95% for each theme. All the disagreements were resolved by discussion to reach consensus.

5 Results and Findings

5.1 Scientists' Views About the Utility of the Family Resemblance Approach to NOS

In response to the first question in the list of questions, all 17 Taiwanese scientists provided positive impressions about the FRA. Statements from 5 scientists are included in this section to provide some examples. One scientist could see the utility of the framework for science education particularly in relation to fostering critical thinking:

> The description in Family Resemblance Approach fits the educational goal in Taiwan: to prepare students for possible participation in sciences and equip with them critical thinking for the scientific enterprise in daily life.

Another scientist appreciated the comprehensive nature of the FRA framework although he was keen to stress that the primary aim of science is solve problems:

> It's a complete and comprehensive framework to illustrate the goal of research in science and demonstrate the relevance between science and other aspects (e.g. society). Despite such understanding, I personally think that the science is just about answering a curiosity-driven unknown problem. In some cases, you even do not know how it can be used. For example, the theory of relativity proposed in 1916 by Einstein. People did not know how it can be used at that time, whereas it is a great case to demonstrate that research in science may need a long time to expose its real value. This is the core of science.

One physicist was particularly keen on elaborating on each FRA category by adding to the core elements a broader set of components that are in interaction although he did not specify what these components might be:

> In general, I agree with the depiction of FRA. It's a good framework to define science, which puts its core value at the center, and surrounded by other interacting elements.

Understandably, scientists were not familiar with the actual terminology of FRA. One scientist stated that he "agree(s) with those descriptions of categories for Family Resemblance Approach but I have no idea when reading the title of Family Resemblance Approach." Another scientist was eager to apply the FRA framework to his own field and illustrate how FRA is relevant for his own research:

> When we explore nanoscience, we certainly will have a set of aims and values. For example, we expect to see novel phenomena when we reduce the size and the dimension of the system. Our goal is to find something abnormal and it usually happens. For granted, we have learned some background knowledge and we have comprehended new phenomena on the nanoscale. To see those novel effects, we will conduct a series of scientific activities.

Hence, the scientist provided "novelty" as an example of cognitive-epistemic aims and values of science. The same scientist continued to detail how the scientific methods and practices would work in nanoscience:

> At least two methods will be adopted to probe the same novel effect. When the new effect is discovered, we will check again and again to make sure that we do see the truth. After we see the new phenomena, we shall analyse it and try hard to explain the background mechanism. We will not announce the novel effect or publish the data immediately. We will think again and again to make sure the meas-

> urement and the effect are reasonable and scientifically acceptable. After confirmation, we could collect data and find the universal regularities. We will try to make sure that the phenomena is universal so we can put it in principles or laws. That is really an end-product of the scientific work.

He went further to explain how the cognitive-epistemic dimensions are complemented with the social-institutional ones in relation to nanoscience:

> After practicing scientific approaches and the new phenomena discovered, there shall be professional activities. Through these activities, the new discovery will be challenged. Others may even doubt that you do not use scientific way to get the result. In addition, the professional activities help to promote the result. The scientific methods shall be reproducible. Others will use the same method to observe the same novel phenomena again.

In the preceding excerpt, the scientist touched on the various FRA categories of *professional activities*, *scientific methods*, and *social certification and dissemination* as defined by Erduran and Dagher (2014). Given the overall positive reception about FRA, the analysis of the written responses to the rest of the questions provided more in-depth illustration of what each scientist thought about every FRA category. In the next section, an analysis of the qualitative responses is complemented with frequency counts of how often the scientists mentioned particular themes related to each FRA category.

5.2 Overall Trends About FRA Themes in Scientists' Views of NOS

Overall, there were 3 to 9 references related to each FRA category in scientists' written texts. The raw numbers about each category along with the percentages are illustrated in Table 4. For each FRA category, the main themes derived from the written data are provided along with a short description of them.

Among the 11 categories, the *ethos* category was the most highlighted by 16 scientists (94%) (see Fig. 2). Except for the *social organization and interactions*, *political power structures*, and *financial systems* categories, others were mentioned by more than 10 scientists (59%). The three least mentioned categories (by 5 or 6 scientists, 29% or 35%) were not included in the descriptions of the 3 physicists. The *social organization and interactions* category was also not proposed by any of the 4 earth scientists.

Most scientists (14 scientists, 82%) referred to more than 6 categories (Fig. 3). This outcome is not surprising considering they were instructed to comment on at least 6 FRA categories. However, which categories they chose to refer to varied. Comparing the 4

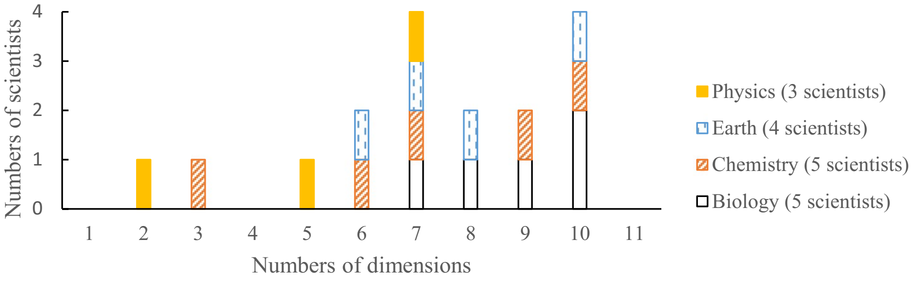

Fig. 3 Number of FRA categories referenced by scientists according to their discipline

sub-disciplines, physicists seemed to refer to fewer FRA categories than those in the other 3 sub-disciplines.

When the scientists' descriptions were examined more closely, further patterns were observed. The number of particular themes related to each FRA category mentioned by the scientists ranged from 2 to 38 themes (Fig. 4). Most of these scientists focused on the categories of the cognitive-epistemic system and the social part of the social-institutional systems, while only about half of them mentioned the characteristics of three categories of the institutional part of the social-institutional system. On average, *practices* and *social values* were the most stressed FRA categories where every scientist mentioned about 3 themes.

The theme "5a. Motivation for engagement" had the highest frequency (15 scientists, 88%), and the theme "2a. Propose reasonable explanations" was the second most frequently mentioned theme (12 scientists, 71%) (Table 4). In addition, 6 themes were proposed by more than half of scientists. Although these scientists are engaged in different fields of science, there was no contradiction among their views about NOS. The fact that the FRA framework was provided to all scientists at the onset of the set of questions ensured that scientists were starting the process of responding about their views of NOS on equal footing. Any differences in the emphases on particular FRA categories can thus be potentially attributed to their individual views.

5.3 Examples of FRA Themes in Scientists' Views of NOS

In this section, we visit the FRA themes in scientists' views of NOS by following each FRA category in more detail. Examples are presented from scientists' written responses. For each category, excerpts from the themes will be quoted to illustrate in more detail how the scientists view the particular aspect of NOS.

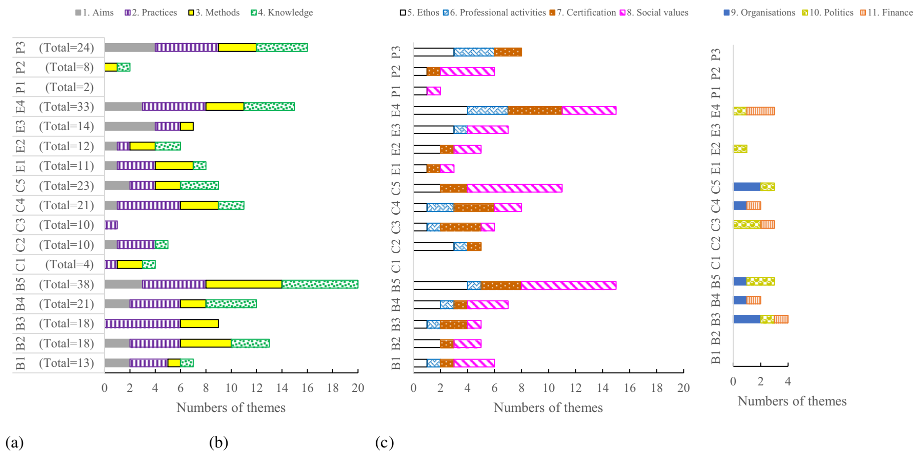

Fig. 4 Number of FRA themes referenced by scientists from different disciplines: a The cognitive-epistemic system. b The social part of the social-institutional system. c The institutional part of the social-institutional system

Table 4 The themes generated from scientists' statements mapped against the FRA categories

Themes related to FRA categories	Description	The numbers and percentages of scientists	
1. Aims and values			
1a. Generate scientific knowledge	There is a lot of unknowns about the regularities of our natural world	8	(47%)
1b. Understand how the natural world operates	The natural world has regularities	6	(35%)
1c. Explore the predictability of scientific knowledge	The operations in the natural world are predictable and traceable via applying the regularities	4	(24%)
1d. Explore coherence	The operations of our natural world are coherent	4	(24%)
1e. Develop understanding of the natural world	The understanding of the natural world can develop through scientific inquiry	2	(12%)
1f. Addressing complexity	The operations of our natural world are complicated	2	(12%)
2. Practices			
2a. Propose reasonable explanations	The explanations of the regularities of our natural world can be proposed in reasonable ways	12	(71%)
2b. Investigate regularity	The regularities of our natural world can be perceived	10	(59%)
2c. Formulate reasoning between explanations and evidence	The explanations of the regularities of our natural world can be justified by extant evidence	10	(59%)
2d. Systemic investigation	The regularities of our natural world can be identified in a systematic way	8	(47%)
2e. Representation of regularities	The regularities of our natural world can be represented	5	(29%)
2f. Argue for the explanations based on evidence	The explanations of the regularities of our natural world can be argued from diverse perspectives	3	(18%)
3. Methods			
3a. No single method	There is no established method to collect data about the uncertain regularities of our natural world	9	(53%)
3b. Certification of evidence	The evidence of the regularities of our natural world can be certified	9	(53%)
3c. Quality of data	The evidence of the regularities of our natural world can be uncovered by accurate and consistent data	6	(35%)
3d. Clarity of evidence	The evidence of the regularities of our natural world needs to be well defined	6	(35%)
3e. Recording of regularities not captured by human perception	Some regularities of our natural world are beyond perception of human beings	4	(24%)
3f. Specificity of conditions	The conditions of operations of our natural world vary by case	2	(12%)

Table 4 (continued)

Themes related to FRA categories	Description	The numbers and percentages of scientists	
4. Knowledge			
4a. Evidence based	Scientific knowledge is verified by sufficient evidence obtained from the rigorous processes of scientific inquiry	9	(53%)
4b. Cognitive aspect of scientific knowledge	Scientific knowledge is acquired through human cognitive activities in the rigorous process of scientific inquiry	7	(41%)
4c. Coherence of knowledge and hypotheses	The proposed reasonable explanations as hypotheses for exploring the regularity are grounded on related knowledge	7	(41%)
4d. Tentativeness of knowledge	Scientific knowledge can be refined, challenged, and even replaced by other explanations that argue from other perspectives	5	(29%)
4e. Systemic coherence	Scientific knowledge is expected to be fitted into a system to provide a coherent account of the natural world	3	(18%)
4f. Constraints of knowledge	Scientific knowledge is constrained by the properties of the regularities being explored and the assumptions and context of scientific inquiry	2	(12%)
5. Ethos			
5a. Motivation for engagement	Engagement in scientific inquiry is usually driven by curiosity, interest, appreciation of the beauty of nature, etc	15	(88%)
5b. Learning from failure	Reflecting on/confronting failure during the process of scientific inquiry is a requisite competence to succeed	5	(29%)
5c. Persistence and ambition	Facing the unknown challenges in scientific inquiry requires ambition, persistence, courage, and so on	4	(24%)
5d. Being honest	Being honest, whether the results are in line with expectations, is a requisite personality when conducting scientific inquiry	3	(18%)
5e. Scrutinizing carefully	Scrutinizing every step in scientific inquiry carefully is a disciplined effort to gain trustworthiness	3	(18%)

Table 4 (continued)

Themes related to FRA categories	Description	The numbers and percentages of scientists	
5f. Open-mindedness	Being open minded, thinking creatively, skepticism, and analogies will help figure out some possible regularities	2	(12%)
5 g. Recognizing bias and prejudice	Paying attention to adjusting the possible bias/prejudice caused by human interference is an expectation when conducting scientific inquiry	1	(6%)
5 h. Respect for the environment	Respecting for humans, organisms, and the environment is a tradition of scientific inquiry that needs to be followed	1	(6%)
6. Professional activities			
6a. Reporting of inquiry	The reports of scientific inquiry need to be faithfully described to be understood and referred	5	(29%)
6b. Critical review	The work of scientific inquiry need to be evaluated critically to reflect on the rigorousness and the soundness of the inquiry	5	(29%)
6c. Exchanging ideas	The scientific progress will be facilitated through idea exchange	5	(29%)
7. Certification and dissemination			
7a. Peer review	Scientific publications rely on the peer review process conducted by experts in the scientific communities	5	(29%)
7b. Public recognition	The publication of scientific inquiry is a means of recognizing scientific achievements and sharing them with the public	5	(29%)
7c. Criteria for professional, ethical, and philosophical issues	Maintaining the stability and quality of scientific practices is based on criteria for professional, ethical, and philosophical issues in scientific inquiry	3	(18%)
7d. Addressing public misconceptions	The dissemination of scientific information is seen as a responsibility of the scientific community to correct public's misunderstandings based on expertise	7	(41%)
7e. Public trust	The dissemination of scientific information is a means to gain the trust and interest of public by explaining comprehensibly the efforts and achievements of the scientific inquiry	6	(35%)
8. Social values			
8a. Expertise in daily life	Scientific expertise can be applied to our daily lives to respond appropriately to certain matters	9	(53%)

Table 4 (continued)

Themes related to FRA categories	Description	The numbers and percentages of scientists	
8b. Improving human life	Scientific expertise helps improve human life by gaining a clearer understanding of the relationships between human society and the world	7	(41%)
8c. Promoting human civilization	Scientific expertise supports the promotion of human civilization	6	(35%)
8d. Judgment based on expertise	Scientific expertise can guide the judgment of the validity of information by understanding the knowledge verification process	6	(35%)
8e. Responsibility for solving problems	Scientific enterprise can take responsibility for addressing real-world problems related to existing entities by using scientific expertise	4	(24%)
8f. Policy decision-making	Scientific expertise with grounded and reasonable understanding can aid in participating in discussions on public issues to make comprehensive policy decisions	4	(24%)
8 g. Being guided by profits	Scientific knowledge may be expected to be commercialized to generate profits	3	(18%)
8 h. Respecting facts	Certain facts utilized in daily life have been proven based on certified evidence collected in scientific inquiry	1	(6%)
8i. Limitation of science	Scientific expertise only helps us to know the regularities of our world, so not all problems in society	1	(6%)
9. Social organizations and interactions			
9a. Cultivate scientific professionals	Establishing a sound science education system and providing progressive instruction and content are essential for cultivating scientific professionals	3	(18%)
9b. Cooperate with different disciplines	Cooperating with different teams or disciplines can promote the progress of science	2	(12%)
9c. Provide employment	Creating a professional employment environment is the basis for the engagement of scientific professionals	2	(12%)
10. Political power structures			
10a. Ideology and policy	The ideology and policy quality of society can influence the direction and regulation of scientific development	3	(18%)
10b. Avoiding suppression	The policy should help construct an active environment to promote the development of science without any suppression	3	(18%)

Table 4 (continued)

Themes related to FRA categories	Description	The numbers and percentages of scientists	
10c. Avoiding bias for special interest groups	Scientific enterprise should be cautious and professional when giving advice on policy making and social issues to avoid bias with special interest groups	2	(12%)
11. Financial systems			
11a. Funding application	Scientific enterprise usually needs to submit a promising proposal to the government or private institutions to obtain financial support for the costs of scientific inquiry	4	(24%)
11b. Independence regarding funding source	It is generally considered that science deserves to be supported, and scientific knowledge and accompanying benefits ultimately belong to all human beings, regardless of where the funding comes from	1	(6%)
11c. Allocation and evaluation of funding	It is necessary to establish an evaluation system to allocate appropriate funds and assess the effectiveness in order to help scientific enterprise develop well	1	(6%)

5.3.1 Aims and Values

Regarding the *aims and values* category, 6 themes were identified from the responses of the 17 scientists. The most mentioned theme in this category was emphasized by 8 scientists (47%) as that science is to "1a. Generate scientific knowledge" (Table 4). For example, one scientist described that *Scientists discover key issues and generate new knowledge (C3).* This theme reflected the most fundamental characteristic of the targets at which science aims—there is a lot that is unknown about our natural world which is worth pursuing to add a new understanding. The second common theme in the *aims and values* category was that science is to "1b. Understand how the natural world operates," as one of 6 scientists indicates (35%): *Science is about understanding the processes of the natural operations (B2).* Two themes emerged from four scientists' responses. One was that science is to "1c. Explore the predictability of scientific knowledge" (24%) and implicated the characteristic of the natural world—the operations in the future world are predictable and traceable via applying the regularities.

The other theme concluded from 4 scientists' responses was that science is to "1d. Explore coherence" (24%), illustrated by the following statement: *The unexplainable or the out of norm anomaly should be pursued. Be able to address the unexplainable leads to the breakthrough in science (E3).* The remaining two themes in the *aims and values* category were mentioned by 2 scientists (12%). Two statements, *Keep updating knowledge (C1),* and *Request the advancement of science (E3)*, denoted that science aims to "1e. Develop understanding of the natural world," and our understanding of the natural world can develop through scientific inquiry. As two scientists (12%) interpreted that science is "1f. Addressing complexity," they recognized that the operations of our natural world are complicated and then scientific inquiry can only approach the truth by using simplified models from different perspectives: *Through science inquiry practices, we are unable to obtain "the correct/final" answer but merely summaries /conclusions of the up-to-date understandings. (E3).*

5.3.2 Scientific Practices

Among the six identified themes in the *scientific practices* category, 3 themes were stressed by more than half of the scientists. The most mentioned practice is to "2a. Propose reasonable explanations" (12 scientists, 71%). Statements such as "With logical reasoning to explain the scientific truth (C3), some characteristics of scientific practices such as explanations of the regularities of our natural world are mentioned. One theme is about the practice to "2b. Investigate regularity" (10 scientists, 59%) which acknowledged the characteristic that the possible regularities of our natural world can be perceived to inspire scientific research questions. For instance, *The importance is about many times of observations and repeatedly confirmation to see the same effect (P1),* and *Observe new thing, then compare them with existing knowledge, find differences and redefine (B3).*

A theme summarized from ten scientists (59%) was that one of the practices of science is to "2c. Formulate reasoning between explanations and evidence." The logic reasoning process had been pointed as the important characteristic of scientific practices: *The correct logic is the basic requirement of scientific research (C1).* More specifically, the proposed scientific explanations should be justified by extant evidence through logical reasoning as illustrated as following statement: *The data obtained should logically support the explanation (C4).*

Another theme in the *scientific practices* category was concluded from eight scientists (47%) in terms of “2d. Systemic investigation.” In these statements, “statistic” and “systematic analysis” had been used to describe a characteristic of scientific practices—in order to identify the regularities of our natural world, the collected data should be interpreted in a systematic way: *Scientific exploration needs to be systematic or using statistical data (B1)*, and *Generate qualitative and quantitative information from analyzing the records to answer the research question (B4).*

A theme mentioned by 5 scientists (29%) is about the practice “2e. Representation of regularities.” Interestingly, “models” and “simulations” were specified by these scientists to illustrate the characteristic of scientific practices—the regularities of our natural world can be depicted in some way to be understood. For instance, *Predict the impact of ocean acidification by a simulation (E2)*, and *Illustrate the system with models (B4).* This theme echoed that the associated relationships between knowledge were expected to fit into a system to provide a coherent account of the natural world which was illustrated in the *knowledge* category below. It is relevant to note that FRA has a particular focus on models and modeling as aspects of scientific knowledge and scientific practices (Erduran & Dagher, 2014) which has not been explicitly mentioned in the consensus view framework which has highlighted the relationship between theories and laws (Lederman et al., 2002).

The last theme in the *scientific practices* category is to “2f. Argue for the explanations based on evidence.” However, argumentation was mentioned as an important practice by only 3 scientists (18%). They indicated the characteristic that the scientific explanations can be diverse from different perspectives and will be challenged through argumentation by comparing different lines of evidence, which was reflected by one of these statements: “Presenting multiple lines of evidence, discuss the importance of these evidence, and distinguish the genuine and unreliable evidence” (B5).

5.3.3 Scientific Methods

The FRA category of scientific methods refers to the methodological approaches (e.g., hypothesis testing, parameter measurement) as well as some methodological rules (e.g., assumptions about methods for instance relevance and limitations of a particular technique). In terms of the *scientific methods* category, 6 themes were identified, and 2 of them were mentioned by 9 scientists (53%). One common theme about scientific methods was that scientists need to “3a. No single method.” These responses, for examples, *Design an experiment or choose the proper methods (E1)*, and *Find appropriate proposals and develop new technologies when necessary (E4)*, made a characteristic prominent by some keywords, such as design, create, and develop. Scientists stressed that there is no established method to explore uncertain natural phenomena, and therefore various methods will be adopted, modified, or created during scientific inquiry. Another common theme (9 scientists, 53%) in the *scientific methods* category was that scientists need to “3b. Certification of evidence.” As the instances below, *That procedure should be reproduced by others completely (E1).* In this theme that scientists need to “3c. Quality of data,” it pointed out the characteristic of scientific method—the evidence of the regularities of our natural world can be uncovered. Data collected from the scientific method should be accurate and consistent in accordance with the hypothesis as evidence to uncover the regularities of the natural world.

Another theme proposed by six scientists (35%) is that scientists need to provide “3d. Clarity of evidence”: *How to identify control variable, independent variable, and dependent* *variable (C2)?* Therefore, a characteristic of scientific methods had been evoked—the evidence of the regularities of our natural world needs to be well defined. Data collected from the scientific method should be appropriate according to the definitions in the hypothesis to be accounted as valid and reliable evidence. A theme related to scientific method is that scientists "3e. Recording of regularities not captured by human perception." Four scientists (24%) acknowledged the facilitation of apparatus or computers and also realized the characteristic of scientific methods—*Some regularities of our natural world are beyond perception of human beings*. Data collected from the scientific method can be processed by some apparatus to explore subtle or complex natural phenomena beyond human perception. For instance, *Selecting the appropriate method, instruments and apparatus for observation is an important issue when conduct scientific inquiry (B4).* A final theme in the *method* category is to "3f. Specificity of conditions." Two responses (12%) indicated the characteristic of scientific methods—the conditions of operations of our natural world vary by case. The assumptions in the context of scientific inquiry should be recognized to conceive of the scope and conditions of the scientific method: *The assumptions and limitation of scientific inquiry need to be discussed. (E1)* The latter reference relates to assumptions about methodology rather than methods directly. As such, it can be classified as part of the "Methods and Methodological Rules" as defined by Erduran and Dagher (2014).

5.3.4 Scientific Knowledge

There were 6 themes in the *knowledge* category; the most common theme was asserted as "4a. Evidence based" by nine scientists (53%). This theme was about the credibility of scientific knowledge—it is verified by sufficient evidence obtained from the rigorous processes of scientific inquiry. This characteristic was reflected by the following statements, *Scientific knowledge is highly credible because it comes from objective and rigorous research methods (E2)*, and *Scientific knowledge must be verified by scientific practice (C3).*

The theme about "4b. Cognitive aspect of scientific knowledge" was proposed by seven scientists (41%). For instances, *Scientists use scientific collection and analysis methods to generate scientific knowledge (B2)*, and *Scientific principles are drawn from scientific practices (B1).* These responses led to the characteristic—scientific knowledge is acquired through human cognitive activities in the rigorous process of scientific inquiry. Derived from 7 responses (41%), the theme "4c. Coherence of knowledge and hypotheses" referred to the characteristic—the proposed reasonable explanations as hypotheses for exploring the natural world are grounded in related knowledge. It was illustrated as follows, *Sufficient relevant background knowledge is necessary as the basis for research ideas and strategies (B1)*, and *With profound knowledge and reasoning, the expected observation of new results can be achieved (P1).*

Another theme was "4d. Tentativeness of knowledge" mentioned by five scientists (29%). However, the theme of tentativeness—scientific knowledge can be refined, challenged, and even replaced by other explanations that argue from other perspectives—was related to the theme of challenges in new discoveries, as exemplified below: *Through the professional activities, the new discovery will be challenged (P1).*

An aspect of scientific knowledge mentioned by three scientists (18%) was systematicity. For example, one scientist stated: *Science is a systematic knowledge, and the system is a collection of many units (B3).* A related but different aspect was systemic coherence: "4e. Systemic coherence" where the emphasis was on scientific knowledge expected to be fit into a system to provide a coherent account of the natural world. An example is as follows: *Science is a way of understanding nature: … connecting various remote concepts to make a coherent view (B5).* The final theme "4f. Constraints of knowledge" was expressed by two scientists (12%). These two responses provided below admitted the characteristic—it is constrained by the properties of the regularities being explored and the assumptions and context of scientific inquiry.

> There are exceptions to the rules of biology, which are different from the theorems of physics and chemistry in the natural sciences. (B3)
> The scientific knowledge or the output of the result is related to the scientific method. Different methods will get different results. (P3)

It should be noted that some of the codes that emerged from the data coincided more directly and explicitly with Erduran and Dagher's (2014) characterization of "scientific knowledge" category while others are more implicit. For instance, the concept of "coherence" is consistent with the coherence that these authors point to among theories, laws, and models, whereas others such as tentativeness of scientific knowledge may not have been phrased explicitly in a similar manner by Erduran and Dagher (2014) even though their framework is inclusive of them.

5.3.5 Scientific Ethos

Eight themes related the *scientific ethos* category were identified. Fifteen of the 17 scientists (88%) emphasized that "5a. Motivation for engagement" is a prime requisite for scientific inquiry and the most important issue in science education. Engagement in scientific inquiry is usually driven by curiosity, interest, appreciation of the beauty of nature, etc. This was reflected by following: *Scientific aesthetics is an important element that attracts people to join science enterprise or to be interested in science. (P3).*

Another *scientific ethos* theme "5b. Learning from failure" (five scientists, 29%) was expressed through the following examples, *The failure of any experiments is the true basis of the scientific society (E3)*, and *Science is trial and error, don't be afraid to make mistakes (B3).* They expressed the characteristic of scientists—reflecting on/confronting failure during the process of scientific inquiry is a requisite competence to succeed. Therefore, a relevant theme "5c. Persistence and ambition" was mentioned by four scientists (24%). The attributes such as ambition, persistence, and courage were included in the statements about scientists' career facing the unknown challenges in scientific inquiry. One scientist indicated the following: *Scientists need to achieve the goal of scientific exploration and scientific discovery with the attitude of scientific truth-seeking and the spirit of seeking the bottom line (B3).* Examples of further *scientific ethos* themes were as below: 5e. Scrutinizing carefully (3 scientists, 18%), 5f. Open-mindedness (2 scientists, 12%), and 5 g. Recognizing bias and prejudice (1 scientist, 6%).

5.3.6 Social Values

In terms of the *social values of science*, 9 themes were identified as exemplified below: (8a) Expertise in daily life, scientific expertise can be applied to our daily lives to respond appropriately to certain matters (9 scientists, 53%), *The scientific way of thinking can apply to any aspect in life (E3)*; (8b) Improving human life, scientific expertise helps improve human life by gaining a clearer understanding of the relationships between human society and the world (7 scientists, 41%), *Science can be used to improve the living environment (C1)*; (8c) Promoting human civilization, scientific expertise supports the promotion of human civilization (6 scientists, 35%), *The fruits of scientific activities are the driving force for leading the rise of human civilization directly and indirectly (B3)*; and (8d) Judgment based on expertise, focusing on the valuing scientific expertise and how it can guide the judgment of the validity of information by understanding the knowledge verification process (6 scientists, 35%), *With what learning from science to judge whether information is worthwhile? Is it reasonable? Is it new? (B3).*

Further themes are as follows: (8e) Responsibility for solving, scientific enterprise can take responsibility for addressing real-world problems related to existing entities by using scientific expertise (4 scientists, 24%), *Science can be used to solve problems. For example, we conducted a project to deal with the agricultural waste problem (C1)*; (8f) Policy decision-making, scientific expertise with grounded and reasonable understanding can aid in participating in discussions on public issues to make comprehensive policy decisions (4 scientists, 24%), *In the case of the nuclear plant referendum, students can discuss the scientific content of the referendum and the scientific rationale of all parties, and have critical thinking (P3)*; (8 g) Being guided by profit, scientific knowledge may be expected to be commercialized to generate profits (3 scientists, 18%), *Recently, there is more weight to the issue of commercializing scientific research results (B3)*; (8 h) Respecting facts, certain facts utilized in daily life have been proved based on certified evidence collected in scientific inquiry (1 scientist, 6%), *Science can prove a fact (B3)*; and (8i) Limitations of science, scientific expertise only help us to know the regularities of how the world operates and not all problems in our society (1 scientist, 6%), *Science can only deal with some problems, not all problems (P3*). The context of the scientist's reference to limitations of science suggested a certain humility about what science can and cannot address, and hence, it is implicitly related to social values. It should be noted that the codes "respecting facts" and "limitations of science" may appear to deviate from Erduran and Dagher's (2014) account given they classified such themes as part of cognitive-epistemic values, whereas we have classified them as being part of social values. We should thus note that the differentiation is a matter of the nuance in the Taiwanese scientists' verbal statements emerging from the empirical data from more extended set of statements, placing more of an emphasis on the social norms of respect and limitations of science in society. Considering the vast amount of data, it is not always possible to provide the full data set with context, but rather we are providing some brief references to the category here.

5.3.7 Professional Activities

The *professional activities* category was mentioned by 5 scientists respectively (29%). For example, scientists referred to "6b. Critical review" and "6c. Exchanging ideas" as follows: *Through these activities, the new discovery will be challenged. Others may even doubt that you do not use scientific way to get the result. In addition, the professional activities help to promote the result (P1)*. These three themes in the *professional activity* category indicated the characteristics of the interactions between scientists and the scientific community: (a) the activities of scientific inquiry need to be faithfully described in the reports, including theoretical background, methods, results, limitations, unresolved issues, and cited references, for others to understand or to refer; (b) the work of scientific inquiry needs to be evaluated critically to reflect on the rigorousness and the soundness of the inquiry; and (c) the scientific progress will be facilitated through idea exchange on professional occasions such as conferences.

5.3.8 Social Certification and Dissemination

In the *social certification and dissemination* category, 3 themes were about the certification by the scientific community. Scientists indicated the following:

> In terms of the publication/publishing of research results, it is usually necessary to go through peer-review in the same research field in order to avoid self-bias of scientists. On the one hand, peer review can objectively comment on the overall research, and if it can be published successfully, it is also an affirmation of the researchers. (C4)
>
> Scientific community and associations are the important platforms for establishing standards. (B4)

Three themes were identified as follows: 7a. Peer review (5 scientists, 29%), 7b. Public recognition (5 scientists, 29%), and 7c. Criteria for professional, ethical, and philosophical issues (3 scientists, 18%). Inferred from the three themes mentioned above, the role of scientific community has three characteristics: (a) scientific publications rely on the peer review process conducted by experts in the scientific communities for fair review, (b) the publication of scientific inquiry through the peer review process is a means of recognizing scientific achievements and sharing them with the public, and (c) maintaining the stability and quality of scientific practices is based on criteria for professional, ethical, and philosophical issues in scientific inquiry. That is, scientific knowledge and the processes it generated are certificated through a publication mechanism followed by the scientific community.

In addition, the dissemination task of scientists and the scientific community was assigned by some scientists and included two themes. The first theme “7d. Addressing public misconceptions” was stressed by seven scientists (41%). The second theme “7e. Public trust” was pointed out by six scientists (35%). These two themes could be identified by one scientist’s words, *Scientific researchers should be responsible for providing the public with the right knowledge. Science needs to make the public aware of the importance and application of science (C1).* Although Erduran and Dagher’s (2014) characterization of the “social certification and dissemination” category focuses on dissemination among scientists, we have here included the engagement and dissemination in the public domain as well, given the emphasis placed by the scientists themselves about how the certification aspects can be important in the public domain. It should be noted however that this is a data-driven decision and does not fully correspond to Erduran and Dagher’s (2014) version of the FRA category.

As one scientist said, *The social impact of correcting the ordinary people’s erroneous audiovisual perceptions should be paid more attention to in science (B2)*, the scientific community plays a role in our society based on the two themes, which can be depicted as (a) the dissemination of scientific information is seen as a responsibility of the scientific community to correct the public’s misunderstandings based on expertise, and (b) the dissemination of scientific information is a means to gain the trust and interest of the public by explaining comprehensibly the efforts and achievements of the scientific inquiry.

5.3.9 Political Power Structures, Financial Systems, and Social Organizations

In related to the social-institutional aspects of the scientific enterprise, a few scientists raised some themes related to the FRA categories of *social organizations and interactions*, *political power structures*, and *financial systems*. There were 3 themes in the *social organization and interactions* category: (9a) Cultivate scientific professionals, establishing a sound science education system and providing progressive instruction and content are essential for cultivating scientific professionals (3 scientists, 18%), *Establish a sound science education system and cultivate true scientific talents. …Teaching content should be in line with the needs of the times (C1)*; (9b) Cooperate with different disciplines, cooperating with different teams or disciplines can promote the progress of science (2 scientists, 12%), *Capitalizing on the development of technology can promote the progress of science (C4)*; and (9c) Provide employment, creating a professional employment environment is the basis for the engagement of scientific professionals (2 scientists, 12%), *With the ever-increasing peer pressure, whether learning science can help increase their income and help them find a good job is a practical issue (B5).*

Three themes regarding to the *political power structures* category were identified: (10a) Ideology and policy, the ideology and policy quality of society can influence the direction and regulation of scientific development (3 scientists, 18%), *Formulating research direction sometimes needs to be coordinated with government policies and social needs (C5)*; (10b) Avoiding suppression, the policy should help construct an active environment to promote the development of science without any suppression (3 scientists, 18%), *Politics should not be a limiting factor affecting science education and research. The policies should not overvalue the commercialization of research results (B3)*; and (10c) Avoiding bias for special interest groups, scientific enterprise should be cautious and professional when giving advice on policy making and social issues to avoid bias with special interest group (2 scientists, 12%), *Science does not serve politics. It cannot be used to repress other scientific research that is inconsistent with your own party (E4).*

In the *financial systems* category, the three themes were as follows: (11a) Funding application, scientific enterprise usually requires the submission of a promising proposal to the government or private institutions to obtain financial support for the costs of scientific inquiry (4 scientists, 24%), *Motivation and purpose are often the most important part of scientific research proposals for research funding (C4)*; (11b) Independence regarding funding source, it is generally considered that science deserves to be supported, and scientific knowledge and the accompanying benefits ultimately belong to all human beings, regardless of where the funding comes from (1 scientist, 6%), *Some private foundations supports science based on human interests (B4)*; and (11c) Allocation and evaluation of funding, it is necessary to establish an evaluation system to allocate appropriate funds and assess the effectiveness in order to help scientific enterprise develop well (1 scientist, 6%), *The soundness of the financial system is related to the ability to support research, and does affect the development of scientific enterprise (E4).*

6 Conclusions and Discussion

The paper reported a study about Taiwanese scientists' views of NOS in general and with respect to FRA in particular.The findings illustrate that scientists considered FRA to be a relevant framework to consider in characterizing NOS and as such, the study provides a rationale for the utility of FRA. Although their individual emphases differed with respect to a particular FRA category, overall, all categories were mentioned across the scientists. Considering that the scientists were provided with very broad characterizations of the FRA categories initially, it is encouraging to see that the way that they unpacked the categories are consistent with how they were conceptualized from a theoretical perspective (Erduran & Dagher, 2014). In other words, scientists' own views and interpretations of NOS were in line with the conceptual FRA categories. In some cases, such as the "scientific knowledge" as well as the "social certification and dissemination" categories, the scientists' statements included aspects that did not necessarily correspond to Erduran and Dagher's (2014) theoretical FRA categories. For example, the scientists stressed the certification and dissemination of scientific information with the public, an idea that is not part of the FRA theoretical framework. However, in order to capture the nuances about the related concepts in each FRA category, we have included the variety of related references to complement the theoretical definitions with empirically derived themes.

Although the scientists mentioned all of the FRA categories collectively, the trends about their relatively lower frequency of reference to social-institutional aspects of NOS are consistent with other studies conducted through use of FRA as an analytical framework. Existing curriculum analyses and textbooks using FRA as an analytical framework from different parts of the world, for instance in Turkey (Kaya & Erduran, 2016), South Korea (Park, Wu, et al., 2020; Park, Yang, et al., 2020), Lebanon (BouJaoude et al., 2017), and Australia (McDonald, 2017), provide a similar account of the relative lower frequency in the attention dedicated to the social-institutional aspects of science. Indeed, this pattern was observed in the recent Taiwanese curricula as well (Yeh et al., 2019). While this finding can be interpreted as curriculum objectives having similar content as what scientists view about NOS, the importance and feasibility for learning of these aspects could be explored in future studies.

Consistent with curricular characterizations of "science is a way of knowing" and "science addressing questions about the natural and material world" (NGSS Lead States, 2013), "creativity and imagination are important elements of science" (Ministry of Education (MOE) 2018), and research studies on scientists' ways of thinking about science (Wong & Hodson, 2010), the scientists in this study highlighted the cognitive and epistemic aspects of science as being central to NOS. However, they were also in agreement with a framework that stresses the social and institutional aspects of science, although these aspects were mentioned to a lesser extent. Nevertheless, the scientists were keen to discuss the scientists' personal engagement in science, along with trustworthiness and powerful impact of scientific knowledge on society. They recognized the responsibility of the scientific community to disseminate scientific information, to gain public trust, and to help promote scientific literacy for judging the validity of information and solving problems. They also remarked that scientific community should be cautious when advising on policy making and social issues.

An aspect of the FRA framework discussed by Erduran and Dagher (2014) is that the particular categories are inter-related, and they can influence each other. For instance, social values can impact the scientific ethos, or financial systems can mediate how epistemic aims and values are determined for scientific research. The interactional and complex nature of science means that it will be difficult not only theoretically but also empirically to assign aspects of science in discrete categories. In terms of methodology, such complexity in delineation of the FRA categories have created some difficulties in coding the themes in the scientists' accounts when there may have been different emphases in the text for more than one interpretation. In other words, in some cases, text could potentially be double counted as an instance of more than one FRA category. We have tried to avoid such inferences by noting the most apparent meaning and emphasis in the written text. Our interpretations as researchers were sent to the scientists for commenting on the coding of their own responses with the FRA categories. The purpose of this final step was to ensure that the researchers' characterization of the scientists' responses was in agreement with how the scientists themselves viewed the main emphasis about FRA in their statements. The primary motivation for checking our interpretations with the scientists was not to seek agreement about the content of the FRA categories or indeed how the scientists themselves may agree or disagree with aspects of NOS more generally, but rather, it was to establish reliability for qualitative data interpretation.

For the purposes of our analysis, further nuance was not entirely necessary given our ultimate purpose was broad about the relevance of FRA from scientists' perspective and not so much about how they might differentiate the different categories of FRA. The fact that the data were in text format also did not enable us to always differentiate the nuance effectively. In future studies, researchers can potentially conduct interactive interviews with scientists so as to clarify the differences in aspects of FRA categories and how the scientists themselves view links between the different categories.

A further limitation of the study is that only 17 Taiwanese scientists were recruited in this study. Although science education in Taiwan is paralleled with those in western countries, and some participants in this study gained their Master's or PhD degrees in western countries, the social and cultural context in Taiwan could influence their perceptions of NOS to some extent. Furthermore, the sample was dominated by male scientists which may pose a gender bias to the responses in the sample. The perceptions of more scientists from different personal backgrounds as well as cultural and educational contexts can be investigated by developing a comprehensive questionnaire based on the results of this study for exploring similarities and differences among various variables with a bigger sample size.

It is possible that with a larger sample size, interpretations from the scientists might be different from perspectives of science educators and philosophers of science. However, the current findings suggest that at least some aspects of NOS are comparable across these different stakeholders for science education striving to establish science as an enterprise broadly based on knowledge, practices, and social context. In one sense, the findings of the study are at odds with previous studies that reported about scientists' lack of reflection about NOS (Bayir et al., 2014). It could be that the visual illustration of the FRA might have encouraged the scientists to have a more reflective account in the written data. However, there isn't sufficient evidence to indicate if scientists' depiction of more fundamental questions of ontology and epistemology of science are consistent with previous studies such as that conducted by Sandoval and Redman (2015) where contradictions were reported.

Future studies can investigate such philosophical undertones of FRA in scientists' views and also explore not only scientists' but also science educators' views of NOS from FRA perspective in a manner similar to Osborne et al. (2003) study that focused on science educators, historians, philosophers, and sociologists of science, science communicators, and science teachers as well as scientists. Although the scientists in this study have diverse disciplinary backgrounds and research interests, they were in agreement about depicting NOS in terms of the FRA categories and they could link the FRA to their own areas of scientific research. The paper contributes to the empirical validation of FRA as a relevant framework from the perspective of scientists and reiterates the characterization of NOS as a cognitive, epistemic, social, and institutional system.

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Declarations

Ethics Approval All necessary ethical approvals were obtained.

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References

Abd-El-Khalick F. (2012). Nature of science in science education: Toward a coherent framework for synergistic research and development. In Fraser B., Tobin K., McRobbie C. (eds) *Second International Handbook of Science Education*. Springer International Handbooks of Education, vol 24. Springer, Dordrecht.

Abd-El-khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education, 22*(7), 665–701.

Akbayrak, M., & Kaya, E. (2020). Fifth-grade students' understanding of social-institutional aspects of science. *International Journal of Science Education, 42*(11), 1834–1861. https://doi.org/10.1080/09500693.2020.1790054

Akgun, S., & Kaya, E. (2020). How do university students perceive the nature of science? *Science & Education, 29*, 299–330. https://doi.org/10.1007/s11191-020-00105-x

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*(3), 518–542.

Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature of science: Integrating student inquiry, historical cases, and contemporary cases in classroom practice. *Science Education, 98*(3), 461–486.

BouJaoude, S., Dagher, Z. R., & Refai, S. (2017). The portrayal of nature of science in Lebanese 9th grade science textbooks. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 79–97). Routledge.

Bayir, E., Cakici, Y., & Ertas, O. (2014). Exploring natural and social scientists' views of nature of science. *International Journal of Science Education, 36*(8), 1286–1312.

Campbell, J. L., Quincy, C., Osserman, J., & Pedersen, O. K. (2013). Coding in-depth semistructured interviews: Problems of unitization and intercoder reliability and agreement. *Sociological Methods and Research, 42*(3), 294–320.

Cheung, K. K. C. (2020). Exploring the inclusion of nature of science in biology curriculum and high-stakes assessments in Hong Kong. *Science & Education, 29*(3), 491–512.

Cotham, J., & Smith, E. (1981). Development and validation of the conceptions of scientific theories test. *Journal of Research in Science Teaching, 18*(5), 387–396.

Couso, D. & Simmaro, C. (2020). STEM education through the epistemological lens: Unveiling the challenge of STEM transdisciplinarity. In, C. C. Johnson, M. J. Mohr-Schroeder & T. J. Moore (Eds.), *Handbook of Research in STEM Education*. Abingdon, Oxon: Routledge.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education, 85*, 554–567.

Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the nature of science for science education: Scientific Knowledge, Practices and Other Family Categories*. Springer.

Erduran, S., Dagher, Z., & McDonald, C. (2019). Contributions of the Family Resemblance Approach to nature of science in science education: A review of emergent research and development. *Science & Education, 28*(3–5), 311–328.

Erduran, S., & Kaya, E. (2019). *Transforming teacher education through the epistemic core of chemistry: empirical evidence and practical strategies*. Dordrecht: Springer

Erduran, S., Kaya, E., & Avraamidou, L. (2020). Does research on nature of science and social justice intersect? Exploring theoretical and practical convergence for science education. In H. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. 97–113). Dordrecht: Springer.

Erduran, S., & Kaya, E. (2018). Drawing nature of science in pre-service science teacher education: Epistemic insight through visual representations. *Research in Science Education, 48*(6), 1133–1149. https://doi.org/10.1007/s11165-018-9773-0

Erduran, S., Kaya, E., Cilekrenkli, A., Akgun, S., & Aksoz, B. (2021). Perceptions of nature of science emerging in group discussions: A comparative account of pre-service teachers from Turkey and England. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-020-10110-9

González-García, F. J., Blanco-López, Á., España-Ramos, E., & Franco-Mariscal, A. (2019). The nature of science and citizenship: A Delphi analysis. *Research in Science Education., 10*, 1007.

Guest, G., MacQueen, K. M., & Namey, E. E. (2012). *Applied thematic analysis*. Thousand Oaks, CA: SAGE.

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education, 36*(15), 2534–2553.

Hodson, D., & Wong, S. L. (2017). Going beyond the consensus view: Broadening and enriching the scope of NOS-oriented curricula. *Canadian Journal of Science, Mathematics and Technology Education, 17*(1), 3–17.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education, 20*(7–8), 591–607.

Irzik, G. & Nola, R. (2014). New directions for nature of science research. In M. Matthews, *International Handbook of Research in History, Philosophy and Science Teaching* (pp. 999–1021). Springer.

Kampourakis, K. (2016). The "general aspects" conceptualization as a pragmatic and effective means to introducing students to nature of science. *Journal of Research in Science Teaching, 53*(5), 667–682.

Kaya, E., Erduran, S., Aksoz, B., & Akgun, S. (2019). Reconceptualised family resemblance approach to nature of science in pre-service science teacher education. *International Journal of Science Education, 41*(1), 21–47.

Kaya, E., & Erduran, S. (2016). From FRA to RFN, or how the family resemblance approach can be transformed for curriculum analysis on nature of science. *Science & Education, 25*(9–10), 1115–1133.

Kelly, R., & Erduran, S. (2019). Understanding aims and values of science: Developments in the junior cycle specifications on nature of science and pre-service science teachers' views in Ireland. *Irish Educational Studies, 38*(1), 43–70. https://doi.org/10.1080/03323315.2018.1512886

Kimball, M. (1968). Understanding the nature of science: A comparison of scientists and science teachers. *Journal of Research in Science Teaching, 5*, 110–120.

Larison, K. D. (2018). Taking the scientist's perspective. *Science & Education, 27*, 133–157.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire (VNOS): Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497–521.

Lederman N. G. & Lederman J. S. (2012). Nature of scientific knowledge and scientific inquiry: Building instructional capacity through professional development. In: Fraser B., Tobin K., McRobbie C. (eds) *Second International Handbook of Science Education*. Springer International Handbooks of Education, vol 24. Springer, Dordrecht.

Matthews, M. R. (2012). Changing the focus: From nature of science to features of science. In M. S. Khine (Ed.), *Advances in nature of science research* (pp. 3–26). Springer.

McComas, W. F., & Olson, J. K. (1998). The nature of science in international science education standards documents. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 41–52). Kluwer.

McDonald, C. V. (2017). Exploring representations of nature of science in Australian junior secondary school science textbooks: A case study of genetics. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 98–117). Routledge.

Ministry of Education (MOE) (2018). *Curriculum guidelines of 12-year basic education: science*. Taipei: MOE.

Mohan, A., & Kelly, G. J. (2020). Nature of science and nature of scientists. *Science & Education, 29*, 1097–1116.

Next Generation Science Standards (NGSS) (2013). *The next generation science standards*. Retrieved from http://www.nextgenscience.org/next-generation-science-standards. Accessed 9 December 2020.

Olson, J. K. (2018). The inclusion of the nature of science in nine recent international science education standards documents. *Science & Education, 27*(7–8), 637–660.

Osborne, J. (2017). Going beyond the consensus view: A response. *Canadian Journal of Science, Mathematics and Technology Education, 17*(1), 53–57.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What ideas-about-science should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40*(7), 692–720.

Park, W., Yang, S., & Song, J. (2020a). Eliciting students' understanding of nature of science with text-based tasks: Insights from new Korean high school textbooks. *International Journal of Science Education, 42*(3), 426–450.

Park, W., Wu, J., & Erduran, S. (2020b). The nature of STEM disciplines in the science education standards documents from the United States, Korea and Taiwan: Focusing on disciplinary aims, values and practices. *Science & Education. Science & Education, 29*(4), 899–927.

Petersen, I., Herzog, S., Bath, C., & FleiBner, A. (2020). Contextualisation of factual knowledge in genetics: A pre- and post-survey of undergraduates' understanding of the nature of science. *Interdisciplinary Journal of Environmental and Science Education, 16*(2), e22115.

Sandoval, W. A., & Redman, E. H. (2015). The contextual nature of scientists' views of theories, experimentation, and their coordination. *Science & Education, 24*, 1079–1102.

Schwartz, R. S., & Lederman, N. (2008). What scientists say: Scientists' views of nature of science and relation to science context. *International Journal of Science Education, 30*(6), 727–771.

Showalter, V. (1974). What is unified science education? Program objectives and scientific literacy (Part 5), *Prisim II,* 2(3+4).

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage.

Wong, S. L., & Hodson, D. (2009). From the horse's mouth: What scientists say about scientific investigation and scientific knowledge. *Science Education, 93*, 109–130.

Wong, S. L., & Hodson, D. (2010). More from the horse's mouth: What scientists say about science as a social practice. *International Journal of Science Education, 32*, 1431–1463.

Yeh, Y., Erduran, S., & Hsu, Y. S. (2019). Investigating coherence on nature of science in the science curriculum documents: Taiwan as a case study. *Science & Education, 28*(3–5), 291–310.

Yucel, R. (2018). Scientists' ontological and epistemological views about science from the perspective of critical realism. *Science & Education, 27*(5), 407–433.