Science & Education
https://doi.org/10.1007/s11191-024-00535-x

ARTICLE

Exploring the Nature of Science Conceptions of University Science Professors Using the Family Resemblance Framework

Rana Issam Baddour[1] · **Saouma BouJaoude**[1]

Accepted: 15 May 2024

Abstract
Over the past few decades, research has been conducted on the nature of science (NOS), which is considered a critical component for achieving scientific literacy. This study aims to explore university science professors' views of NOS using a recent theoretical framework, which is the family resemblance approach (FRA). FRA is a comprehensive framework that presents NOS in terms of cognitive-epistemic and social-institutional systems, including eleven categories. Only two studies used the FRA as an analytical tool to explore scientists' views about NOS. Consequently, this study extends the emerging literature on the FRA by exploring the NOS conceptions of science professors in the Lebanese context. The study used a mixed-methods approach and involved 35 professors teaching science-technology- and engineering-related subjects. Results obtained from a modified version of the reconceptualized FRA questionnaire as well as semi-structured interviews revealed that the NOS conceptions of the science professors are in line with the FRA framework. While the categories of the cognitive-epistemic system were the most highlighted in the professors' responses, categories of the social-institutional system were less addressed. Interestingly, a new theme related to epistemic affect emerged in the interviews of two professors. The findings discuss practical and pedagogical implications for instruction and recommend future areas for research.

1 Introduction

Nature of science (NOS) has been a proliferating area of research in science education since the 1960s. The inclusion of NOS aspects in the science curriculum has been endorsed in recent reform documents across the world (National Research Council., 2012; Next Generation Science Standards [NGSS] Lead States, 2013; Organization for Economic Cooperation and Development (OECD), 2017). This was justified based on the rationale that achieving scientific literacy requires an adequate understanding of NOS.

✉ Rana Issam Baddour
rib09@mail.aub.edu

Saouma BouJaoude
boujaoud@aub.edu.lb

[1] Department of Education, American University of Beirut, P.O. Box 11-0236, Riad El-Solh, Beirut 1107 2020, Lebanon

Published online: 29 May 2024

Several definitions were given to the construct NOS by the science education community, yet "it most commonly refers to the values and assumptions inherent to the development of scientific knowledge" (Lederman, 1992, p.331). As a result, diverse philosophical models emerged to conceptualize NOS, one of which was the "consensus view." The "consensus view" was characterized by seven key ideas about science which are empiricism (scientific knowledge relies on observations), tentativeness (scientific knowledge is never absolute rather it is subject to change), subjectivity (scientific knowledge is influenced by the scientists' background, experiences and beliefs), creativity (generating scientific knowledge involves human imagination and creativity), social and cultural embeddedness (scientific knowledge is influenced by the larger social and cultural context), the distinction between theories and laws (theories and laws are different kinds of scientific knowledge and one does not become the other), and the distinction between observations and inferences (observations are descriptive statements about a certain phenomenon that are directly accessible to senses while inferences are statements about a phenomenon that are not directly accessible to the senses). Additionally, this view emphasized that there is no single scientific method that all scientists use to produce knowledge (Abd-El-Khalick, 2012; Lederman, 2007; McComas, 2004). The "consensus view" NOS list just described achieved wide agreement among philosophers, sociologists, and science educators for its relevance to NOS teaching in K-12 classes. Moreover, it informed the development of a widely used instrument; the VNOS (Views of the Nature of Science) questionnaire to assess the degree of NOS understanding (Lederman et al., 2002).

Despite this, the "consensus view" was challenged for several reasons. Some scholars critiqued it for being "universal" and argued for a move towards a "particularistic approach" of NOS to help students appreciate the diversity that exists across and within the different scientific disciplines (Rudolph, 2000). Others argued that the "consensus view" ignores the role of model-building and advocated for engaging students in domain-specific scientific practices to enhance their science learning (Grandy & Duschl, 2007). Further critiques were also provided by Clough (2007) who suggested shifting the declarative statements about NOS into questions to promote discussion about NOS. As a result, alternative perspectives were proposed including the "whole science" approach suggested by Allchin (2011), who argued for the inclusion of a set of dimensions that represent the foundations of reliability in scientific practice, and that are absent from the "consensus view" NOS list. These dimensions include, among others, the role of funding, motivations for doing science, social interactions among scientists as in the peer review process, the validation of new instruments and experimental practices, the influence of cultural factors on science such as the ideological, religious, gender, and racial issues, and different forms of misconduct. Another perspective was offered by Matthews (2012) who advocated for replacing NOS with "features of science" (FOS) to expand its scope beyond the focus on scientific knowledge. These features involve both epistemic aspects (experimentation, explanation, theory choice, and rationality) and philosophical aspects (feminism, realism, and constructivism).

A more recent conceptualization of NOS was provided by the philosophers Irzik and Nola (2011a, 2011b, 2014) as an alternative to the "consensus view." It is called the "family resemblance approach" (FRA) based on Wittgenstein's (1958) linguistic philosophy, which used the analogy of family resemblance to show that not all "words" can be bound to specific features or functions. A similar issue arises with attempts to define the term "science." Science involves various disciplines such as physics, biology, chemistry, zoology, botany, and astronomy, and it is hard to find specific characteristics that are shared by all these scientific disciplines. Henceforth, by applying Wittgenstein's idea of family resemblance to NOS, Irzik and Nola (2011a, 2014) treated the various scientific disciplines as members of a "family" having certain common characteristics (domain-general), yet there exist other characteristics that are unique to each discipline (domain-specific). To clarify this further, Irzik and Nola (2014) provide the example of experimentation, among other practices, to show that even though experimentation is a common characteristic shared by many scientific disciplines, it is restricted in a discipline like astronomy or earth science. Therefore, unlike the "consensus view," the FRA framework accommodates both the domain-general and domain-specific characteristics of science. While the FRA framework subsumes all aspects proposed by the alternative NOS models, it excludes part of Matthew's "features of science" model specifically, the philosophical commitments including realism, feminism, and constructivism. This makes the FRA a philosophically neutral model and hence gives it an attractive feature (Irzik & Nola, 2014).

Following this, Erduran and Dagher (2014a, 2014b) reconceptualized the philosophical FRA framework of Irzik and Nola by extending and transforming it for pedagogical purposes in science education. Several terms were used to distinguish Erduran and Dagher's expanded FRA version from its philosophical counterparts (Irzik and Nola's FRA version and Wittgenstein's family resemblance idea) such as expanded FRA, extended FRA, and "Reconceptualized FRA-to-NOS or (RFN)" which was firstly used by Kaya and Erduran (2016, p.1118). The current study chose the "family resemblance approach" (FRA) as its theoretical foundation. A detailed description of the FRA framework is provided in the section below.

2 Literature Review

2.1 Theoretical Framework: Family Resemblance Approach (FRA) to Nature of Science

The FRA framework had several versions since its introduction into the science education research literature. In their original version, Irzik and Nola (2011a) focused on four categories that reflect the cognitive aspects of science: activities, aims and values, methodologies, and methodological rules, as well as products. In a revised version (2011b; as cited in Erduran & Dagher, 2014a, 2014b), they introduced a fifth component of social context, including social values, research ethics, and Merton's norms, which involve the norms that scientists should follow while conducting their work, such as universalism, organized skepticism, disinterestedness, and communalism. Later, Irzik and Nola (2014) transformed the fifth component into a social-institutional dimension including four categories: professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values.

In a more recent version, Erduran and Dagher (2014a, 2014b) expanded the FRA framework of Irzik and Nola by adding three categories under the social-institutional system of science. These are social organizations and interactions, political power structures, and financial systems. The additional categories serve a wider range of learners especially those who are not attracted to the cognitive aspects of science. Moreover, they highlight the fact that science is also a "social endeavor," which is influenced by several social and cultural factors. The inclusion of the various cognitive, epistemic, and social aspects of science and their articulation in a wholesome manner gives the FRA its comprehensive and systematic nature.

Another significant contribution of the expanded FRA model was the introduction of the "Generative Images of Science" (GIS) which are visual tools that help communicate key ideas about NOS and inform its pedagogical and instructional implications. Provided below is a brief description of the eleven FRA categories (Erduran & Dagher, 2014a, 2014b).

1. *Aims and Values (AV):* refers to the set of aims and cognitive values in the sense that the products of science are desired to fulfill them including making predictions, providing explanations, consistency, objectivity, falsifiability, and accuracy.
2. *Scientific Methods (SM):* includes the various reasoning strategies that scientists use to produce reliable scientific knowledge including inductive and deductive reasoning as well as manipulation of variables.
3. *Scientific Practices (SP):* includes the diverse set of processes used in scientific inquiry such as making observations, posing questions, and constructing models.
4. *Scientific Knowledge (SK):* refers to the products of scientific activities such as laws, theories, and models.
5. *Professional Activities:* involves the various professional activities that scientists perform among which are attending academic meetings, presenting findings, seeking funds, and reviewing grant proposals.
6. *Scientific Ethos:* includes the social and ethical norms that scientists should abide by while conducting their work or interacting with other scientists such as intellectual honesty, openness, and respect for colleagues and the environment.
7. *Social Certification and Dissemination of Scientific Knowledge:* refers to the peer-review process, evaluation, and criticism.
8. *Social Values:* includes freedom, respect for the environment, and social utility to improve people's health and quality of life as well as to contribute to economic development.
9. *Social Organizations and Interactions:* includes the organizational structures and interactions among scientists and relational transactions within and among scientific communities.
10. *Political Power Structures:* refers to the relationships between science and its political ends and who benefits from them.
11. *Financial Systems:* involves issues of funding that are mediated by economic factors, and which enable, control, or limit the distribution of resources in science as well as the nature of the research conducted.

The FRA approach to NOS raised new questions for research in science education. As a result, different empirical themes emerged all of which provide evidence about the framework's utility and effectiveness in improving the quality of science teaching and learning. For instance, some studies used the framework as an analytical tool to identify the occurrence of the NOS aspects in science curricula (Erduran & Dagher, 2014b; Kaya & Erduran, 2016; Tairab et al., 2023; Yeh et al., 2019) and science textbooks (BouJaoude et al., 2017) or to elicit teachers' views (Azninda et al., 2021) and students' views (Akgun & Kaya, 2020) about NOS. Other studies used the framework as an instructional tool and tested the effectiveness of an RFN-based intervention on teachers' understanding of NOS (Cullinane, 2018; Erduran et al., 2020; Kaya et al., 2019).

Regardless of the approach used to conceptualize NOS, teachers have an important role to play in conveying to students an adequate image of NOS, which is a critical component of scientific literacy (Lederman, 1992; Organisation for Economic Cooperation & Development, 2017). To date, a substantial body of research has explored the NOS conceptions of K-12 students and preservice and in-service science teachers, and the results continue to show that both students and teachers possess inadequate understanding of NOS (BouJaoude, 1996; BouJaoude & Santourian, 2010; Lederman, 2007; Lederman & Lederman, 2014). However, limited studies were conducted with university science professors to identify their NOS conceptions. These professors are scientists who are experts in their fields and perform research in their related disciplines. They are responsible for educating future citizens including those majoring in scientific or non-scientific fields and others who will contribute to the development of their societies. For this reason, they have to have adequate conceptions of NOS and be willing to communicate them effectively to their students, thus preparing them to become scientifically literate individuals. Therefore, exploring the NOS conceptions of university science professors is desirable.

2.2 Research on University Science Professor's Views of NOS

Previous studies conducted with scientists compared their NOS views to those of teachers and students (Behnke, 1961; BouJaoude, 1996; El-Khoury et al., 2014), and reported that scientists hold mixed conceptions of NOS which are often traditional ones. Such traditional views suggest that science aims to reveal factual truths about the world. Other studies explored the relationship between scientists' views of NOS and their scientific disciplines and areas of research (Bayir et al., 2014; Schwartz & Lederman, 2008; Ssempala, 2015). These studies also reported mixed conceptions that had no relation with the scientists' disciplines. The third line of research conducted with university science professors investigated the extent to which these professors incorporate NOS aspects in their instruction (Karakas, 2009; Woitkowski & Wurmbach, 2019). These studies revealed that professors prefer traditional teacher-centered strategies even though they are aware of the importance of incorporating these aspects into their teaching practices.

Most of the aforementioned studies used the VNOS (Views of the Nature of Science) questionnaire as a survey instrument to assess the degree of NOS understanding (Lederman et al., 2002). The VNOS questionnaire reflects a "consensus view" towards conceptualizing NOS, which was criticized for being narrow in scope. As discussed by Dagher and Erduran (2023), the FRA does not contradict the seven "consensus view" tenets, but rather considers additional NOS aspects that were not made explicit by the "consensus view" and articulates them in an interrelated, wholesome manner.

Only two studies used the FRA as an analytical tool to explore scientists' views about NOS. The first study was conducted by Wu and Erduran (2022), who investigated how scientists view NOS in general and from an FRA perspective. Participants were 17 Taiwanese scientists (16 males and 1 female) whose ages ranged from 41 to 65 years. Those scientists specialized in different disciplines (biology, earth science, chemistry, and physics) and were keen on science communication and outreach. Data were collected by using five open-ended questions. To ensure equality, the participants were provided with brief definitions of the eleven FRA categories and a picture of the FRA wheel at the onset of the questions. The written responses were analyzed qualitatively (constant comparison method) and quantitatively (frequency count of the mentioned FRA themes). The results indicated that all the scientists' views were in line with the FRA framework since they detailed all aspects of NOS. However, the social-institutional aspects were underrepresented in the scientists' depiction.

In the second study, Peters-Burton et al. (2023) reexamined data obtained from a previously conducted study by Peters-Burton and Baynard (2013) that investigated the NOS views of three different groups of participants which included Grades 7 and 8 students, middle school teachers, and scientists, using the FRA as the new theoretical approach. The statements identified from the participants' responses to four open-ended questions about the nature of knowing and the nature of knowledge were reclassified based on the FRA theoretical framework into their resultant FRA categories. Next, these statements were interpreted using the *epistemic network analysis* (ENA). The ENA involves grouping the qualitative statements into clusters of ideas, quantifying them by frequency counts, and then creating a network model to show connections among resultant ideas. The results revealed that among the three groups of participants, scientist network models revealed more connections across their statements, indicating a higher level of agreement and coherence among a variety of NOS ideas as captured in the FRA framework. Therefore, the current study extends the emerging literature on the FRA by exploring the NOS conceptions of university science professors in a different context; the Lebanese context, by answering the following research question:

- What are the conceptions of university science professors regarding the nature of science as conceptualized in the family resemblance approach (FRA) in the Lebanese context?

3 Methodology

3.1 Sample

The sample consisted of thirty-five scientists selected from a private university in which English is the medium of instruction. These scientists are university professors who earned a Ph.D. and have a professorial-academic rank at the university including assistant professors, associate professors, and full professors. They are experts in their fields and perform research in their related disciplines. The scope of this study was not only restricted to natural science professors from the Faculty of Arts and Sciences (FAS), but rather faculty members who teach science-technology and engineering-related subjects were also included. As such, the professors were selected from five faculties which are the Faculty of Agricultural and Food Sciences (FAFS), Faculty of Arts and Sciences (FAS), Faculty of Medicine (FM), Faculty of Health Sciences (FHS), and Faculty of Engineering and Architecture (FEA).

3.2 Data Collection Tools and Procedures

This study adopted a mixed-methods design including the collection of both quantitative and qualitative data. The quantitative data were collected by using a modified version of the "RFN Questionnaire," which was originally developed by Kaya et al. (2019) and modified following discussions with two experts in the science education field, one of whom is the co-author of the expanded FRA. It was agreed that the positive item # 51 in the "aims and values" category, which states that "Teaching epistemic, cognitive, social and cultural values should be the core components of the science curriculum," and the negative item # 39 in the "social-institutional systems" category, which states that "Intellectual honesty in science does not have to be taught in science lessons" (Kaya et al., 2019), be moved to the "educational applications" category since they are related to teaching and the curriculum. Additionally, all the items related to the "educational applications" category, which are sixteen in total, were not included in the modified questionnaire since the purpose of this study was to explore the NOS conceptions of university science professors rather than how these professors consider the teaching aspects of RFN. However, the instrument reviewers recommended including questions about the excluded category in the follow-up interviews, especially since the study aims to draw the attention of these professors to the need to address the NOS aspects in their instruction. Hence, the modified "RFN questionnaire" included 52 items and used a 5-point Likert-type scale (Totally Disagree, Disagree, Not Sure, Agree, Totally Agree) reflecting the five RFN categories: "aims and values," "scientific practices," "scientific methods," "scientific knowledge," and "social-institutional systems." For each RFN category, there were positive and negative items. For example, the "aims and values" category includes seven items, five of which are positive (2, 20, 40, 51, and 69) and two of which are negative items (46 and 56). Additional demographic items related to the participants' gender, age, disciplinary area, highest degree earned, and total years of teaching experience were also included in the questionnaire (see Appendix Table 1). The questionnaire was administered online using the Lime survey, which is an online survey tool. The online questionnaire was sent to two-hundred-forty-one faculty members of all ranks through email. Only thirty-five complete responses were received (Response Rate = 14.52%). Out of the thirty-five professors, twenty-seven were males and eight were females, which is representative of the professors' gender distribution at the chosen university. The number of professors per faculty was as follows: thirteen professors from FAS, eight from FEA, seven from FM, five professors from FAFS, and two from FHS. A full description of the demographics of the participating professors with their corresponding scores on the questionnaire is presented in Appendix Table 2.

For the qualitative data, follow-up interviews of the semi-structured type were used as the primary data-gathering instruments to provide an in-depth understanding of the science professors' views about NOS in general and from an FRA perspective in particular. Eleven professors out of the thirty-five (31.42%) surveyed accepted to be interviewed, which according to Lederman et al. (2002) is sufficient to validate the questionnaire responses. Their distribution per faculty was as follows: four professors from FAS, two from FM, two from FAFS, two from FEA, and one from FHS. As for the interview questions, they were divided into three sets. The first set included theory-driven questions based on the FRA framework. The second set of questions requested elaborations on specific items in the modified questionnaire including item 6 (universal scientific method), item 7 (science as a social system), items 13 and 32 (forms of scientific knowledge), and items 18 and 25 (forms of scientific practices). The third set of questions targeted the "educational applications" category to explore how professors think about teaching the NOS aspects, and the extent to which they address them in their classrooms (see Appendix 7). The interviews were conducted face-to-face in the professors' offices except for two, which were done virtually via Zoom. All the interviews were audio-recorded, transcribed verbatim afterward, and then subjected to analysis.

3.3 Data Analysis

The reliability of the administered questionnaire was established by calculating Cronbach alpha ($\alpha = 0.69$), which is acceptable. A code was assigned for each participant which included the abbreviation of the professors' corresponding faculty, the letter P, and a number count for each participant within the same faculty (e.g., FAS-P1). A similar strategy to the one used by Kaya et al. (2019) was adopted to calculate the participants' scores from the questionnaire. First, the selection of the options for each item was coded. The options of "totally agree," "agree," "not sure," "disagree," and "totally disagree" were coded as 5, 4, 3, 2, and 1, respectively. For the negative items, the codes of "5," "4," "2," and "1" were re-coded as "1," "2," "4," and "5," respectively. Recoding is a common approach in the interpretation of questionnaire data. Data were entered into SPSS to calculate the overall score for each participant. To obtain a deeper understanding of the professors' NOS ideas, the percentage of professors who responded to the questionnaire items by category and level of agreement or disagreement was then computed and compared.

For the qualitative data, the transcribed interviews were analyzed using the deductive coding approach (Linneberg & Korsgaard, 2019) in search of indicative text segments (codes). The resultant codes were compared against a coding frame that included the definitions as well as indicative keywords of the eleven FRA categories as described by Erduran and Dagher (2014a, 2014b). Henceforth, each code was assigned to its corresponding FRA category (Aims and Values-AV, Scientific Methods-SM, Scientific Practices-SP, Scientific Knowledge-SK, professional activities, scientific ethos, social certification and dissemination, social values, social organizations and interactions, political power structures, and financial systems), as well as the system to which it belongs whether cognitive-epistemic (CE) or social-institutional (SI). Later, the analysis of the text segments was complemented with frequency counts to determine how often the participating professors referred to the FRA categories. The repeated codes were not counted. It is important to note that the code-identification process was guided by how the professors responded to each question. Any emerging themes were also reported. Therefore, the frequency count was based on the professors' responses to all the interview questions. To ensure the reliability of the data collected from the follow-up interviews, the transcribed interviews, the coding process, and the resultant codes were reviewed by an expert in the science education field.

4 Results and Findings

4.1 Quantitative Results

The total scores on the modified "RFN questionnaire" ranged from a minimum of 176 to a maximum of 220, with a mean value of 193.51 rounded to 194 (SD = 10.686), which is an average absolute score[1] of 3.73 per item. This absolute score revealed that the professors tend to agree with the questionnaire items, indicating that their NOS conceptions are in line with the FRA framework. More specifically, Fig. 1 shows the distribution of the professors' responses across the five RFN categories by levels of agreement or disagreement.

[1] Average absolute score is computed by dividing the average RFN score (194) by the number of questionnaire items (52).

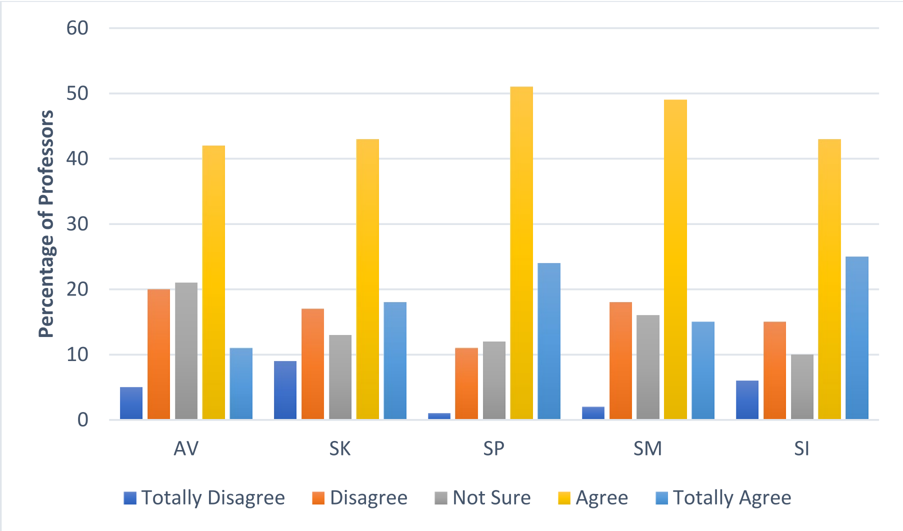

Fig. 1 The distribution of the professors' responses across the five RFN categories by levels of agreement or disagreement. *Note*. AV Aims and Values, SK Scientific Knowledge, SP Scientific Practices, SM Scientific Methods, and SI Social and Institutional system

As shown in Fig. 1, there seems to be an uneven distribution in the level of agreement and disagreement of professors with the FRA framework. While the majority of the professors agree with almost all the items of the five RFN categories, the highest consensus was on the "scientific practices" and "scientific methods" categories (both having 51% and 49% agreement respectively). This indicates that these categories are apparently valued by the professors. Moreover, the highest levels of uncertainty and opposition were in the "aims and values" category, with 21% of professors indicating "Not Sure" and 20% indicating "Disagree."

4.2 Qualitative Results

4.2.1 General Trends About FRA Categories in the Professor's Responses

The frequency of occurrence of each FRA category as referenced by the eleven interviewed professors is provided in Fig. 2. Overall, the eleven FRA categories were addressed by the interviewed professors, who appear to be cognitively oriented especially since the three top frequency counts (133 for SP, 64 for AV, and 54 for SK) are for the categories within the cognitive-epistemic system. However, across the two systems, the results reveal that the "scientific practices" category is the most prominent category ($f=133$) in the cognitive-epistemic system, and the "social values" is the most highlighted category in the social-institutional system ($f=45$).

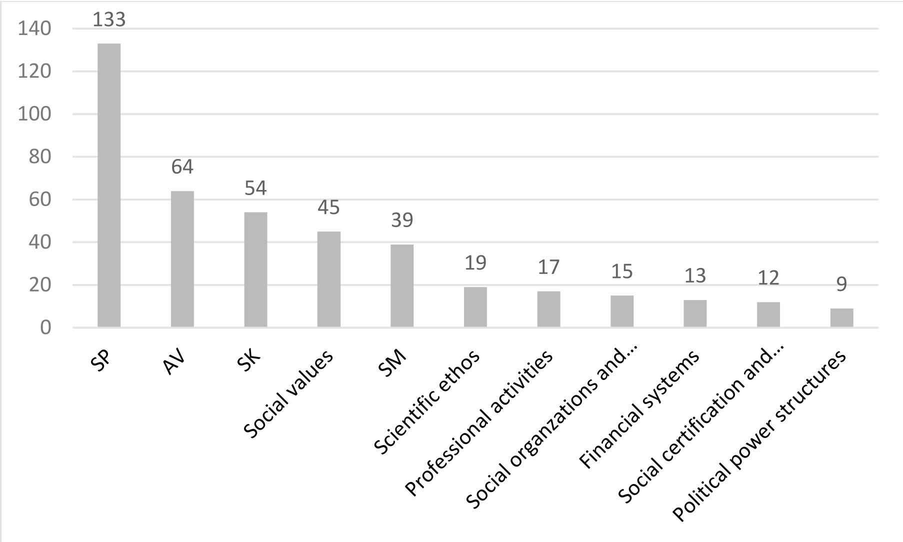

Fig. 2 Overview of the results showing the frequency of occurrence of each FRA category in the professors' responses. *Note.* AV Aims and Values, SM Scientific Methods, SP Scientific Practices, and SK Scientific Knowledge

4.2.2 A Detailed Examination of the FRA-NOS Conceptions of University Science Professors as Revealed by the Interviews

4.2.2.1 Question Set 1. General Questions The first question set was composed of three general questions targeting the FRA theoretical framework.

Definition of Science of Science The majority of the science professors (73%) revealed a cognitive-epistemic orientation when asked about the meaning of science. Following are some excerpts from their responses: "Mainly, a method to find robust explanations for observable phenomena." (FAS-P12), "It's an informed process" (FEA-P1), and "Traditionally, there is the scientific method where you would try to search and find information which is reproducible, which can be analyzed, which can lead to other similar information that will define how things operate, how things work" (FM-P4). On the other hand, 3 of the 11 professors (27%) addressed the social aspects of science while defining it. More specifically, they highlighted the "social values" category in the FRA framework and explained how science can improve people's health and quality of life as illustrated in the following excerpt: "Science is cure and practical solutions to problems and by science we need to save our planet and provide therapies for humans, improve the human race, and importantly to preserve our environment and our planet Earth" (FM-P3).

Distinction Between Science and Other Forms of Inquiry In response to the second question on what distinguishes science from other forms of inquiry, the majority of the science professors based their justification on the "aims and values" category, where 9 out of the 11 professors (82%) emphasized the fundamental characteristics that science aims to satisfy as being imperative to distinguish it from other forms of inquiry. The most stressed items were empirical adequacy followed by objectivity and reproducibility which are illustrated in the following excerpts respectively: "the evidence-based nature of the data that makes it different from philosophy" (FEA-P8); "There's no interference of personal ideas or anything" (FAFS-P2); and "in life there is a tendency with science to only accept what can be reproduced" (FM-P4). The second most highlighted justification was based on the "scientific practices," where 8 of the 11 professors (73%) referenced the various strategies involved in scientific inquiry such as data collection, experimentation, and observations among others as essential characteristics of science. For example: "Science is more related to things that you discover, that you analyze, that you see with your own eyes." (FHS-P2). On the other hand, 3 of the 11 professors (27%) referenced social aspects of science and emphasized the "scientific ethos" category, including the norms that scientists should abide by while conducting their work, as being distinctive features of science. For example, some professors stated that "aesthetics plays a big role in what idea is appealing to us and how we shape our ideas" (FAS-P12) and that "we need to be open-minded to accept any output" (FM-P3).

Social and Institutional Aspects of Science When the professors were given the chance to discuss the social aspects of science, they provided rich explanations about the various social-institutional categories within the FRA framework. Ten out of the 11 professors (91%) mentioned the "social values" category with an emphasis on addressing societal needs and improving living conditions. Other categories of the social-institutional system of the FRA framework were on average addressed by 2 out of the 11 professors (18%). These include "professional activities" as illustrated in the following excerpts: "when you patent" (FAS-P5), and "when we see on the internet some calls for research for application" (FAS-P7), "social certification and dissemination of scientific knowledge" cited in "peers are people working on similar subjects that you are working and therefore can evaluate whether your work is going to benefit the group or not and move science forward" (FM-P4), "social organizations and interactions" such as "science is going to be related to what the institution has objectives to work on, to guide its researchers, to do these kinds of things" (FHS-P2), "political power structures" affirmed in "if you look at science in Germany in the 30 s right where there were lot of biologists who built a scientific framework for the racists ideology which we find now horrifying right?"(FAS-P12), and "financial systems" such as "I mean governments who have found the benefits of scientific discoveries OK had allocated a certain amount of funds a percentage of the tax collected to be spent on research" (FM-P4). The least referenced category was the "scientific ethos" which was voiced by only one professor as: "the umbrella under which you are doing your science where there is also ethics" (FAS-P5).

4.2.2.2 Question Set 2. Elaboration Questions The second question set was composed of elaboration questions by which the professors were asked to clarify their choices on specific questionnaire items. These questions can be grouped into four major themes:

Forms of Scientific Knowledge Several professors stated that there is a hierarchical relationship between scientific theories and laws and that theories become laws with sufficient confirmation. For example, "Laws are higher-up, more verifiable" (FEA-P8), and "Laws… are actually theories that have been confirmed experimentally" (FAS-P13). Despite possessing this traditional hierarchical view, those professors were keen on communicating the idea that scientific knowledge is never absolute, rather it is subject to change as illustrated in this excerpt: “I would put laws on top of theories. Laws are when we have so many theories, it’s well established you come up with a law. Theories, you test a theory…. There are no absolute laws…The biggest discoveries happened when the central dogmas were broken” (FM-P3).

As for scientific models, several professors identified them as tools rather than forms of scientific knowledge. For example, “Models help us understand the science but they are not knowledge per se” (FAS-P13), and “Scientific models are like the base…a template…a representative of a certain phenomenon” (FHS-P2). Another professor was able to capture the explanatory power of models when admitting that: “The sense of doing science is the sense of model building and you have to have a model to be able to make predictions…. in Biology I would say the prime example of model building is Mendel, Mendel’s genetics” (FAS-P12). Moreover, the existence of different types of models was also addressed by one of the professors who explained it as follows:

> It can be a process-based model where there are physics involved or math. It can be simple model as in and out and I am knowing what is happening inside so I am not able to understand the phenomenon itself but I understand how an out reacts to an in. And there is a third part which is a completely statistical model where I don’t even try to reproduce what is happening inside. I am just looking at a certain inference of an output from an input based on pure statistics. (FAS-P5).

Universal Scientific Method When the professors were asked to elaborate on the existence of a universal scientific method, they admitted the use of the traditional-standard scientific inquiry method while emphasizing experimentation to produce reliable knowledge. This is illustrated in the following excerpts: “There are precise methods to follow in science…. All branches of science have the same step-to-step method to doing science.” (FAFS-P2), and “I am an experimental scientist, the essence of science is observation and measurements and interpretation and in all four the basic sciences geology, physics, chemistry and biology, observation, measurements, and analysis are common core to all of them” (FAS-P13).

Forms of Scientific Practices The majority of the professors admitted that “observation” and “experimentation” are fundamental scientific practices across all scientific fields where they stated that: “A good scientist has to be a very good observer” (FAFS-P2), and “for me science is experimentation” (FAS-P7). Meanwhile, only one professor believed that in some cases observation doesn’t apply, but other types of scientific practices such as inferences is required, as explained in: “we have the theoretical science…You use observations but you infer things that have happened in the past based on observations that are happening now. This is not direct observation this is indirect” (FAS-P5).

Science as a Social System When asked to justify the description of science as a social system, the professors reflected on all the dimensions within this system. Again, they emphasized the social utility of science as stated by one of the professors: “Everything that we are doing from models, experiments serve some purpose either improves quality of life, improves safety, efficiency, reduces cost in one way or another there has to be some practical application” (FEA-P8). However, when considering the “political power structures” dimension, the professors had contradictory views. While some professors addressed the view of non-subjectivity in science whereby factors like race, gender, and ethnicity don't affect its outcome, as evident in the following excerpts: "A scientist can be from any place in the world, any race that shouldn't affect the outcome" (FM-P3), and "I don't think that gender, race, ethnicity, whatever should have an influence on what you can do with science" (FEA-P8); others believed that science is subjective which they expressed as follows: "We see science as hard-core basic science as molecules interacting…but in our interpretation you can always sense the baggage that a person has carried over his/her lifetime and obviously gender makes a big difference" (FAS-P13), and "Everything that is part of the person of the scientist influences how they do science including the gender" (FAS-P12).

Furthermore, some professors acknowledged the interplay among the different dimensions within the social system where they discussed how the "financial systems" impact the scientists' "professional activities" within "social organizations." This was evident in the following excerpt:

> The university takes, when NIH or when the NSF funds, scientist cost includes salaries for people working (post-doctoral fellows, assistant professors, research assistants), lab facility, equipment, supplies and trips to attend conferences, costs of publication. This is the cost of a scientist, the investment that the NIH would put. (FM-P4)

4.2.2.3 Question Set 3. Educational Applications The third question set was about the educational utility of the FRA framework. It included the most questions especially that the items related to the "educational applications" category were omitted from the modified RFN questionnaire to be covered in the individual interviews.

Teaching Students About Scientific Aims and Values to Promote Scientific Literacy All the professors acknowledged the importance of incorporating aspects of the "aims and values" of science in their teaching. Considering the epistemic-cognitive aims and values, several professors emphasized empirical adequacy and reproducibility as illustrated in the following excerpts: "When I ask them to reproduce the experiment… they are aware that data should be accurate, data should be reproducible, otherwise we cannot say that these data are publishable or serve the causes" (FAS-P7). In terms of social norms and cultural values, the majority of the professors stressed scientific integrity and ethics as crucial aspects of any scientific activity. For example, "In our PhD programs, we require an ethics course, but ethics is part of any teaching of any scientific inquiry" (FM-P3). Moreover, some professors mentioned that the aim or value of science lies behind addressing societal needs as illustrated in the following excerpt: "Why are we looking for the next fastest most effective computer system or algorithms or way of treatment for a certain disease so…. if you understand the aims you may help in finding better solutions" (FEA-P1).

Understanding the Scientific Methodology to Distinguish Science from Non-science All the interviewed professors believed that understanding the scientific methodology helps students distinguish between science and non-science. Several professors pointed out that they communicate with students the view of a standard scientific method to generate evidence-based explanations, as illustrated in "when they see the methodology that we have used they will definitely be more convinced of what is really scientific what have passed the test of the scientific method" (FAS-P13). One professor admitted the use of the other methodological forms including the historical dimension of science as illustrated in:

"I teach biochemistry…for nursing and for graduate students, I always start my lecture, first lecture, by giving them the biggest discoveries in history. That would give them a feel…of the scientific advancements" (FM-P3). However, it was not clear whether the professor discusses with students how these historical data were obtained or how they relate to other existing scientific data.

Engaging Students in Discussions About Experimental Data All the interviewed professors were aware of the importance of engaging students in discussions about experimental data and how science develops with time. Several professors reported that they stressed issues of reproducibility and validity in these discussions such as: "you have to determine uncertainty on this result, you have to reproduce this result and you cannot provide a result without an uncertainty" (FAS-P7). On the other hand, some professors referenced a variety of constraints that prevent them from running such discussions in the science classroom, and believed that these discussions are better done in seminars. They mentioned the constraints of time and curriculum as follows: "The problem is that often in our physics courses, the curriculum is so large….it doesn't give us enough room to discuss these issues that are somehow seen outside of the curriculum" (FAS-P13), and "Not as much as I should… You look at your calendar and you see very little time slots available" (FEA-P1).

Integration of Social and Cultural Aspects of Science in Teaching When the professors were asked whether they integrate social and cultural aspects of science in their teaching, the majority emphasized the use of real-life examples that are relevant to the material being taught. For example: "I teach Chemistry 202 which is Introduction to Environmental Chemistry for engineering students and you are talking about atmospheric pollution, about water pollution, water treatment, how to avoid atmospheric pollution, etc.…. I give them real examples, how these examples are affecting our life" (FAS-P7). Some professors claimed to have incorporated various social and cultural aspects of science in their teaching including social awareness, financial systems, political power structures such as gender, as well as social organizations and interactions. One of them claimed the following:

> I teach…plant nutrition and soil chemistry. I want my students to be able to design a fertilization program for different crops and then…the economics of it, of not only producing higher yield, is it economical to go to the highest yield? And then, livelihood of that producer, the farmer, and how much that farmer would make money out of it and from there how we go to food security. (FAFS-P2)

Remarkably, an emerging theme, which was not previously reported in studies with scientists, was detected in the interviews of two professors in the interviews. In one of the responses about what science is, a professor from the FM replied by saying: "Science is discoveries, passion we should have passion for science" (FM-P3). As such, this excerpt was coded as an emerging theme related to "epistemic affect," an area that involves the affective experiences that occur for scientists while they engage in disciplinary work. In another response about the influence of gender on doing science, a professor from the FAS replied as follows:

> Positively actually. I see it positively since I …. have come to realize that I am a backward thinker… So, I think that, also the intuition has a say, for instance how to

set a hypothesis, it's your feeling of your surrounding that makes you set a hypothesis, while maybe other people need the data to set a hypothesis. I could have a hypothesis and go fetch the data because I am in connection with my environment a lot, I feel it, and because I collect a lot of data so in the end, I am in connection with the spring that I am monitoring or the well so this is where I but at the end everyone has to get to the point of data and to proving. (FAS-P5).

5 Discussion and Conclusion

The quantitative findings revealed that the NOS conceptions of the science professors are in line with the FRA framework with varying degrees of agreement across the five RFN categories. On the other hand, the qualitative findings allowed for a better depiction of the NOS conceptions of the interviewed professors. These findings agree with Wu and Erduran (2022), in that the scientists addressed the eleven FRA categories while mainly focusing on the cognitive-epistemic aspects of NOS. For instance, most professors described science as an empirical, testable, and experimental endeavor that exhibits a self-correcting nature.

Moreover, the underrepresentation of the social-institutional FRA categories in the current study is consistent with other studies that also used the FRA as an analytical tool. For instance, studies that analyzed the occurrence of NOS aspects in curricula and textbooks across different contexts including Turkey (Kaya & Erduran, 2016), Lebanon (BouJaoude et al., 2017), Australia, and Taiwan (Yeh et al., 2019), and the UAE (Tairab et al., 2023). Additionally, the professors in this study were eager to talk about how science affects society and its growth, as well as the ethical principles by which scientists should abide when carrying out any scientific activity. They were also aware of their duty as a scientific community to convey scientific information to the public in a simplified, comprehensible manner. Henceforth, the variability in the representation of the RFN categories was consistent across both the quantitative and qualitative findings. Despite this variability, the professors' responses to the interview questions revealed an interconnectedness within and across the eleven FRA categories. This finding is consistent with Peters-Burton et al. (2023), who revealed that scientists show coherent ideas about the FRA categories.

Considering the emerging theme of "epistemic affect," this finding agrees with the results of an ethnographic study conducted by Osbeck et al. (2011), which involved fifteen participants, including scientists, in two biomedical-engineering laboratories at a large research university. The analysis of interviews and observational data revealed an entanglement of the cognitive, affective, social, and cultural dimensions of scientific practice. These dimensions are considered part of science and drive persistence on tasks whether in professional or normal classroom settings (Davidson et al., 2020). Accordingly, the emerging theme reported in this study is worth considering, especially that "care for motivation and affective dimensions of learning" is one of the principles that guided Erduran and Dagher's conceptualization of NOS (Erduran & Dagher, 2014a, 2014b, p.2). Besides, "epistemic affect" is a new field that is gaining prominence in the science education literature. Currently, exploring the "affective experiences" of scientists remains understudied compared to the studies conducted with students and teachers for the same purpose (Davidson et al., 2020; Jaber & Hammer, 2016).

This study has some limitations that are worth considering in future studies. The first limitation arises from selecting the professors from the same university, although they were professors teaching science-engineering-and-technology related subjects across five different faculties (FAS, FM, FAFS, FHS, and FEA) at the selected university. Accordingly, increasing the sample size by including other universities can help ensure more representative results. Another limitation is the sampling technique used, which was on a voluntary basis. As a result, the professors who volunteered to participate in this study are not representative of other university science professors within their various disciplines. Therefore, the findings of the study cannot be generalized. A third limitation stems from the theoretical framework itself. As discussed by Erduran and Dagher (2014a, 2014b), the generative nature of the FRA framework might be thought of as being complex since it places heavy demands on the science curriculum. However, they argue for using the content of the science curriculum in a way that motivates a wider range of learners even those who are not attracted to the cognitive aspects of science.

Future studies can include classroom observations, which can help reveal additional details about the FRA-NOS conceptions of the participating professors and the extent to which they incorporate these NOS aspects in their teaching practices. Another recommendation is the need to explore the "affective experiences" of science professors which will help provide insights into the cultural diversity of science as advocated by the FRA framework. Finally, further studies are needed to understand how and where "epistemic affect" can be situated within the FRA framework.

To conclude, the current study builds on calls for increasing empirical research on the utility of the FRA framework. It does so by exploring the NOS views of university science professors using the FRA in a different context; the Lebanese context. It is important to note that in Lebanon, having a teaching diploma is not a mandatory requirement for hiring science professors at the university level. Moreover, science at the undergraduate level still emphasizes the product (content) over the process. This was evident from the interviews when the professors discussed the constraints for effective implementation of NOS in their teaching among which is the demanding curriculum. For this reason, the current study calls for a nationwide evaluation of university scientific curricula and the creation of a framework that equips science professors with the necessary pedagogical skills to help them refine their teaching methods and explicitly address NOS aspects in their instruction. Some universities in Lebanon took the lead and implemented a "Certificate in Teaching in Higher Education" which provides PhD students with the necessary skills in teaching methodologies, syllabus design, and learning outcomes among others. Accordingly, this study encourages such university-led initiatives and urges them to plan and implement FRA-based interventions that would help communicate the required understanding of the FRA approach and equip science professors with the necessary skills to explicitly address the FRA categories in their teaching. This will help improve the quality of science teaching and make it more accessible and appealing to students, even those not majoring in science, thus contributing to a scientifically literate society.

6 Appendix 1

Table 1 Modified RFN questionnaire

Questionnaire items	Totally Disagree	Disagree	Not Sure	Agree	Totally Agree
1. Epistemic, cognitive, and cultural values of science cannot be distinctly distinguished from each other	☐	☐	☐	☐	☐
2. Scientific knowledge does not change	☐	☐	☐	☐	☐
3. Scientists review and assess each other's work	☐	☐	☐	☐	☐
4. The power of experimentation comes from testing a scientific hypothesis many times by scientists	☐	☐	☐	☐	☐
5. Science takes place in institutions such as universities and research centers	☐	☐	☐	☐	☐
6. All scientific disciplines such as physics, biology, and chemistry use the same scientific method	☐	☐	☐	☐	☐
7. Science is a social system	☐	☐	☐	☐	☐
8. Scientific progress occurs when ideas are evaluated and revised	☐	☐	☐	☐	☐
9. Each branch of science has a different nature	☐	☐	☐	☐	☐
10. Politics does not influence science	☐	☐	☐	☐	☐
11. Scientists should respect the environment	☐	☐	☐	☐	☐
12. Analysis and interpretation of data are components of scientific practices	☐	☐	☐	☐	☐
13. Theories and laws are forms of scientific knowledge but models are not	☐	☐	☐	☐	☐
14. Scientists don't have to share their research with society	☐	☐	☐	☐	☐
15. Scientists build and use models to understand complex scientific phenomena	☐	☐	☐	☐	☐
16. The diversity of scientists solving a problem together means less biased results	☐	☐	☐	☐	☐
17. There is no step-by-step order to doing science	☐	☐	☐	☐	☐
18. All branches of science use observations	☐	☐	☐	☐	☐
19. Diversity of methods contributes to scientific understanding	☐	☐	☐	☐	☐
20. All hypothesis testing is manipulative	☐	☐	☐	☐	☐
21. Some branches of science do not use representations	☐	☐	☐	☐	☐

Table 1 (continued)

Questionnaire items	Totally Disagree	Disagree	Not Sure	Agree	Totally Agree
22. Scientists have to use different methods to produce enough evidence so that they can solve problems	☐	☐	☐	☐	☐
23. Scientific knowledge consists of a coherent set of ideas	☐	☐	☐	☐	☐
24. Scientists need money to do research	☐	☐	☐	☐	☐
25. Classification helps scientists explain and predict phenomena	☐	☐	☐	☐	☐
26. All scientific disciplines such as physics, biology, and chemistry produce values that can contribute to society	☐	☐	☐	☐	☐
27. The gender of scientists influences how they do science	☐	☐	☐	☐	☐
28. There is a universal scientific method that all scientists use all over the world	☐	☐	☐	☐	☐
29. Scientific experiments follow a certain set of procedures	☐	☐	☐	☐	☐
30. Scientists should change their minds when they realize that their ideas are not supported by evidence	☐	☐	☐	☐	☐
31. Policies of governments affect the growth of scientific knowledge	☐	☐	☐	☐	☐
32. Laws are theories that are confirmed	☐	☐	☐	☐	☐
33. Scientific models are tools to represent the real world	☐	☐	☐	☐	☐
34. Some scientists earn more money than others, causing tension between scientists	☐	☐	☐	☐	☐
35. Scientific facts are not affected by bias and individual subjective prejudices of scientists	☐	☐	☐	☐	☐
36. Race and ethnicity of scientists have nothing to do with science	☐	☐	☐	☐	☐
37. Changing variables is a fundamental requirement for a scientific study	☐	☐	☐	☐	☐
38. Theories, laws, and models work together to produce scientific knowledge	☐	☐	☐	☐	☐
39. Different branches of science like physics, biology, and chemistry have the same practices	☐	☐	☐	☐	☐
40. Scientists write papers in academic journals	☐	☐	☐	☐	☐
41. There are different kinds of theories. Some are accepted; others are still debated	☐	☐	☐	☐	☐
42. There is no relationship between scientific facts and values	☐	☐	☐	☐	☐
43. Scientists from all branches of science validate scientific knowledge by evaluating each other's ideas	☐	☐	☐	☐	☐

Table 1 (continued)

Questionnaire items	Totally Disagree	Disagree	Not Sure	Agree	Totally Agree
44. Scientists participate in conferences to share their research with other scientists	☐	☐	☐	☐	☐
45. All scientific disciplines such as physics, biology, and chemistry require constructing hypotheses	☐	☐	☐	☐	☐
46. There are standards for evaluating the quality of scientific work	☐	☐	☐	☐	☐
47. Models can help scientists to explain and predict phenomena	☐	☐	☐	☐	☐
48. Scientific practices produce knowledge and are not influenced by cultural factors	☐	☐	☐	☐	☐
49. Laws are more verifiable scientific knowledge than theories	☐	☐	☐	☐	☐
50. There are social hierarchies among science teams and these can change	☐	☐	☐	☐	☐
51. Scientific aims and values affect scientists' choice of methods in their investigations	☐	☐	☐	☐	☐
52. Scientists socially interact with other scientists while doing research	☐	☐	☐	☐	☐

Adapted from Kaya et al. (2019)

7 Appendix 2 Interview questions

7.1 Question Set 1: General questions driven by the FRA theoretical framework

1. What, in your view, is science? (Schwartz & Lederman, 2008)
2. What makes science or a scientific discipline (biology, physics, etc.) different from other disciplines of inquiry (religion, philosophy, etc.)? (Schwartz & Lederman, 2008)
3. What comes to your mind when I say social and institutional aspects of science? Can you give any examples? (Akgun & Kaya, 2020)

7.2 Question Set 2: Elaboration questions

Participants will be asked to clarify their choices on the following questionnaire items: 6,7, (13–32), and (18–25).

7.3 Question Set 3: Educational applications

1. Do you integrate social and cultural aspects of science in your teaching?
   - a If so, how often and for what purposes?
   - b If not, justify your choice?
2. Do you think that the science curriculum should not only cover scientific knowledge but also the social and cultural aspects of science? Justify your choice.
3. Do you think that teaching students about scientific aims and values improves their scientific literacy?
4. Do you think that it makes a difference to students' learning of science if they engage in discussions about experimental data, or how knowledge develops in science?
   - a If so, how often do you engage them in such discussions and for what purposes?
   - b If no, justify your choice.
5. Do you think that understanding scientific methodology can help students distinguish between science and non-science?

(Questions 4 to 8 are based on the RFN questionnaire items of the "educational applications" category).

8 Appendix 3

Table 2 Demographic data about the participating professors with their corresponding questionnaire scores ($N=35$).

Faculty	Code	Gender	Age	Disciplinary area	Highest degree earned	Years of teaching experience	Total RFN score
FAS	FAS-P1	Male	50	Chemistry	PhD	19	199
	FAS-P2	Male	58	Natural Science	PhD	18	176
	FAS-P3	Female	58	Biology	PhD	26	184
	FAS-P4	Male	49	Biology	PhD	19	186
	FAS-P5	Female	41	Geosciences	PhD	10	183
	FAS-P6	Male	56	Natural Science	PhD	25	216
	FAS-P7	Male	47	Environmental/Instrumental/ Chemistry	Habilitation	22	192
	FAS-P8	Male	57	Sciences/Chemistry	PhD	22	205
	FAS-P9	Male	36	Basic Science	PhD	7	220
	FAS-P10	Male	60	Chemistry	PhD	30	188
	FAS-P11	Male	47	Biology	PhD	15	186
	FAS-P12	Male	51	Biology	PhD	11	188
	FAS-P13	Male	57	Physics	PhD	25	201
FM	FM-P1	Male	61	Medicine	MD	29	188
	FM-P2	Male	42	Microbiology	PhD	13	203
	FM-P3	Female	59	Biochemistry & Molecular Genetics	PhD	23	200
	FM-P4	Male	78	Internal Medicine (Endocrinology) & Pharmacology	MD	50	186
	FM-P5	Female	41	Translational Research (Hematology /Oncology & Parasitology)	PhD	20	205
	FM-P6	Female	49	Medicine	PhD	15	189
	FM-P7	Female	51	Cancer Biology	PhD	14	197
FHS	FHS-P1	Male	62	Public Health	DrPH	30	185
	FHS-P2	Male	37	Medical Imaging	PhD	5	200

Table 2 (continued)

Faculty	Code	Gender	Age	Disciplinary area	Highest degree earned	Years of teaching experience	Total RFN score
FAFS	FAFS-P1	Male	65	Food Science	PhD	33	210
	FAFS-P2	Male	76	Soil Science	PhD	44	189
	FAFS-P3	Male	65	Agriculture	PhD	35	188
	FAFS-P4	Male	59	Nutrition	PhD	33	187
	FAFS-P5	Female	45	Agriculture	PhD	6	180
FEA	FEA-P1	Male	45	Civil Engineering	PhD	14	212
	FEA-P2	Male	40	Engineering	PhD	11	200
	FEA-P3	Male	54	Engineering	PhD	20	197
	FEA-P4	Male	56	Architecture	Master	20	183
	FEA-P5	Male	56	Engineering	PhD	30	184
	FEA-P6	Male	44	Chemical Engineering	PhD	12	194
	FEA-P7	Male	49	Electrical & Computer Engineering	PhD	18	183
	FEA-P8	Female	33	Industrial Engineering	PhD	7	189

Acronym FAS-P1 stands for the abbreviation of the professors' corresponding faculty (FAS), the letter P (Participant), and a number count for each participant within the same faculty.

Acknowledgements We would like to thank all the professors for their time and willingness to share their experiences with us. This work would not have been possible without their contribution.

Declarations

Ethics Approval Ethical approval to conduct the study was granted by the Institutional Review Board of the university.

Conflict of Interest The authors declare that they have no conflict of interest.

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