Comparison of Physics, Chemistry and Biology Teachers' Perceptions of Nature of Science and Domains of Science

Ebru Kaya, Bogazici University, Turkiye
Sibel Erduran, University of Oxford, UK

Abstract

The paper presents an empirical study on physics, chemistry and biology teachers' perceptions of nature of science (NOS) and domains of science. Reconceptualised Family Resemblance Approach to NOS (RFN) was used as a theoretical framework and informed the data analysis approaches. RFN inherently considers both domain-general and domain-specific features of NOS, and thus it is an appropriate framework to address the main research problem about different subject teachers' perceptions of NOS. Using quantitative and qualitative methods, we trace how the teachers perceive different categories of RFN including scientific knowledge and practices. Although the teachers' gender, teaching experience and education level do not contribute to any variation in their perceptions of NOS, their subject-matter specialisms influence how they view different RFN categories. This observation is corroborated through some of the findings from the qualitative data analysis which provides detailed variations among the teachers indicating a complex set of relations between the similarities and differences among teachers' perceptions across subject specialisms. Future research can extend the methodological approaches utilised in this paper to include for example, in-depth interviews to explicate further the nuances across the subject teachers' views of NOS in relation to domains of science.

Introduction

Science teachers' perception of nature of science (NOS) is a well-investigated area of research in science education (e.g., Lederman & Lederman, 2019; Capps & Crafward, 2013; Herman & Clough, 2016). NOS is often defined as the values and assumptions fundamental to science and its knowledge development, including tentativeness of scientific knowledge as well as the cultural and social embeddedness of science (Lederman, 1992). Put another way, NOS refers to the epistemological, ontological, and sociological aspects of science (Clough & Olson, 2008). Given NOS is a component of many science curricula from around the world (e.g., McComas & Olson, 2002), science teachers' perceptions of NOS are instrumental for the implementation of curriculum content at the level of the classroom.

It has long been recognised that science teachers' subject background as well as their NOS perception influences their teaching (Lederman et al., 2002; Magnusson, Borko & Krajcik, 1999). Teachers not only need to understand the subject knowledge but also be able to apply it in pedagogical scenarios for the purposes of teaching and learning (Borko, 2004). According to Shulman (1986), teachers' knowledge can be conceptualised as two main components: content knowledge (CK), which represents an understanding of the subject matter and pedagogical content knowledge (PCK), which represents the pedagogical aspects required to teach the subject matter, such as knowledge about students' cognition, and practical exercises (p. 9). It is assumed that CK is a crucial prerequisite for the acquisition of PCK and both knowledge facets are mainly acquired during the university phase of teacher training (Depaepe, Verschaffel, & Kelchtermans, 2013). As part of CK, teachers' perceptions of NOS can shape how they view the nature of their subject matter from an epistemological point of view and subsequently influence how they teach science (Akerson et al., 2006).

Another aspect of teachers' knowledge concerns their disciplinary background in terms of the science domain that they have been trained in as well as their epistemic beliefs about different domains of science. Much research in cognitive sciences point to the importance of domain-specificity of scientific reasoning given epistemic beliefs may be shaped differently in different domains (e.g., Muis et al., 2006). Muis et al. (2006) focusing on 19 empirical studies concluded that epistemic beliefs should be regarded as both domain-general and domain-specific. Numerous comparisons have been made of how epistemic beliefs differ across domains (Aditomo, 2018). Such comparisons have often contrasted personal epistemologies in relation to different disciplines such as physics and biology (Lee & Tsai, 2012). Since science teachers' subject background as well as their NOS perception influences their teaching (Lederman et al., 2002), it is important to understand how science teachers perceive domain-general and domain-specific characteristics of science.

In this paper, we thus investigate physics, chemistry and biology teachers' perceptions of NOS. We focus on the Family Resemblance Approach (FRA) to NOS (Erduran & Dagher, 2014) because by definition, it is inclusive of domain-specific characterisation in NOS (Irzik & Nola, 2011) and we are interested in exploring domain-specific characteristics of teachers' perceptions of NOS. It is important to compare different subject teachers' perceptions of NOS in order to ensure that teacher education can enhance disciplinary ways of reasoning and knowing. For example, geosciences are characterised by their particular application of and reliance on temporal and spatial reasoning (Ryker et al., 2018). Geoscientists must be able to apply their knowledge across a variety of scales, an aspect of scientific reasoning that may not be emphasised in the same way and to the same extent, for instance, in biology. Following a review of the literature on NOS focusing primarily on FRA and science teachers' perceptions of NOS, we present an empirical study on secondary Turkish physics, chemistry and biology teachers to trace how they compare in their perceptions and comparisons of NOS including their own subject matter expertise. Our approach can have implications for the broader international community in identifying effective professional development approaches to enhance science teachers' teaching of NOS based on understanding of their perceptions of NOS.

Nature of science in science education

Nature of Science (NOS) has been a curriculum objective in science education for many years (Hodson, 2016; Lederman et al., 2002). Historically, various accounts of NOS have been reported in the science education research literature. An early study by Chang et al. (2010) traced the literature between 1990 and 2007. The key proponents during this period in science education (Abd-El-Khalick 2012; Lederman et al. 2002; McComas and Olson 1998) have outlined a set of statements that characterise what has been referred to as a "consensus view" of NOS which has guided various science education efforts. For example, using the consensus view of NOS, McComas (2014) reviewed the NOS components of state standards in the USA. Alternative perspectives on NOS have also emerged including the idea of "Whole Science" (Allchin 2011), "Features of Science" (Matthews 2012), and the "Family Resemblance Approach (FRA) to NOS" (Irzik & Nola, 2014, 2011). A recent systematic review by Cheung and Erduran (2023) on FRA highlighted that there has been increasing interest in investigations about how FRA can be of use in science education both empirically and practically. In 2023, a special issue of Science & Education was dedicated to the applications of FRA in science education (Barak, 2023).

Within NOS research in science education, FRA is unique in that it incorporates the notion of domain-specificity by definition. The starting point for this perspective on NOS is the need to justify why a domain is considered ‘science’, and indeed why different fields such as chemistry, biology and physics can all be considered ‘science’. In contrast to the other mentioned perspectives which highlight NOS in a fairly domain-general manner, FRA uses an analogy of a family to illustrate that like a biological family, some members of the family of sciences will resemble each other (i.e., domain-generality) but also will also differ (i.e., domain-specificity). For example, although observation is common to all science disciplines, the precise nature of observation and what counts as evidence may be unique in different fields of inquiry. Irzik and Nola (2014) present the example of observation (i.e. human or artificial through the use of detecting devices) and argue that even though observing is common to all the sciences, the very act of observing is not exclusive to science and therefore does not necessarily grant family membership. The same applies to other practices such as inferring and data collecting, which are shared by science fields, but their use is not necessarily limited to them.

Erduran and Dagher’s (2014) account of FRA provides a comprehensive representation of different aspects that characterize the scientific enterprise. The original account of FRA was primarily philosophical in nature (e.g., Irzik & Nola, 2011). Erduran and Dagher (2014) extended Irzik and Nola’s (2011) account of FRA by adding some categories to the social-institutional dimension and their framework is described below:

1. Aims and values: The scientific enterprise is underpinned by adherence to a set of values that guide scientific practices.
2. Practices: The scientific enterprise encompasses a wide range of cognitive, epistemic, and discursive practices.
3. Methods and methodological rules: Scientists engage in disciplined inquiry by utilizing a variety of observational, investigative, and analytical methods to generate reliable evidence.
4. Knowledge: Theories, laws, and models are interrelated products of the scientific enterprise that generate and/or validate scientific knowledge and provide logical and consistent explanations to develop scientific understanding.
5. Professional activities: Scientists engage in a number of professional activities to enable them to communicate their research, including conference attendance and presentation, writing manuscripts for peer-reviewed journals, reviewing papers, developing grant proposals, and securing funding.
6. Ethos: Scientists are expected to abide by a set of norms both within their own work and during their interactions with colleagues and scientists from other institutions.
7. Social certification and dissemination: By presenting their work at conferences and writing manuscripts for peer-reviewed journals, scientists’ work is reviewed and critically evaluated by their peers.
8. Social values: The scientific enterprise embodies various social values includ- ing social utility, respecting the environment, freedom, decentralizing power, honesty, addressing human needs, and equality of intellectual authority.
9. Social organizations and interactions: Science is socially organized in various institutions including universities and research centers.
10. Political power structures: The scientific enterprise operates within a social and political environment that imposes its own values and interests.

11. Financial systems: The scientific enterprise is mediated by economic factors that influence research priorities, and who benefits from the produced knowledge.

FRA has been applied in empirical investigations on analysis of assessments (Cheung, 2020) and textbooks (BouJaoude, Dagher & Refai, 2017) as well as teachers' engagement with NOS from FRA perspective (e.g., Erduran et al., 2021). Some research has focused on particular FRA categories such as scientific methods (Wei, Jiang & Gai, 2021) and social-institutional aspects (Akbayrak & Kaya, 2020). Some researchers have capitalised on the FRA perspective to investigate the content of curricula in different countries such as Turkey (Kaya & Erduran, 2016), Norway (Mork et al., 2022) and Taiwan (Yeh et al., 2019). A recent special issue of the journal *Science & Education* has been dedicated to the use of FRA in science education, covering a range of themes from teaching and learning to curriculum analysis (Barak, 2023).

Kaya and Erduran (2016) coined the term "Reconceptualised FRA to NOS" (or RFN) to emphasise such educational adaptations of the framework proposed by Erduran and Dagher (2014). In other words, RFN is the same framework as the one proposed by Erduran and Dagher (2014). Although the RFN has an inherent capacity to differentiate NOS in different subject domains by its very definition, this aspect of the framework has been under investigation in science education research, particularly in relation to teachers' perceptions of NOS. In the rest of this paper, we will use the RFN terminology when we discuss science teachers' perceptions of NOS in the context of the empirical study. Next, we turn to a discussion of the broader research literature on science teachers' perceptions of NOS.

Science teachers' perceptions of nature of science

The quality of science teaching can be influenced by various factors including teachers' perceptions of NOS (Lederman & Lederman, 2019). Abd-El-Khalick and Lederman (2000) argued that effective teachers should have adequate understanding of both NOS and pedagogy. These authors highlighted that the teaching of NOS requires a broad knowledge base associated with activities, examples, performances, and demonstrations, which enable teachers to organise, represent, and introduce NOS in a form that is accessible to students. Given the importance of NOS understanding for teaching quality, it is important to study science teachers' NOS understanding which may be related to other factors such as gender (Taale, 2014).

There is extensive research that illustrates the limitations of science teachers' NOS understanding. For example, Dogan and Abd-El-Khalick (2008) have demonstrated that many science teachers often come with the notion that when a hypothesis is proven correct, it becomes a theory and when a theory is proven correct, it becomes a law. Some science teachers view scientific theories as less secure than laws (Akerson et al., 2006). Similarly, Aslan and Taser (2013) demonstrated that Turkish science teachers expressed naive conceptions about the relationships between hypotheses, theories, and laws. Some science teachers assume that scientific knowledge becomes more stable with more evidence (Ma, 2009) while others perceive models as copies of realities (Guerra-Ramos et al., 2010). In terms of the scientific method, some science teachers view the scientific method as a fixed step-by-step method or believe in the recipe-like process of doing science (Mesci & Schwartz, 2017). Many science teachers also view scientists as free of biases and prejudices (Prachagool & Nuangchalerm, 2019); and creativity and imagination are not perceived as relevant to scientists (Akerson & Donnelly, 2008).

Some researchers investigated teachers' perceptions of NOS in relation to gender and academic background, reporting that there is no significant relationship between science teachers' gender and their conceptions of the NOS (Saif, 2016; Taale, 2014). For instance, the descriptive survey carried out by Adedoyin and Bello (2017) concluded that a similar proportion of male and female secondary science teachers maintained a traditionalist and a constructivist view of the NOS. In their study of the 201 Turkish science teachers, Yaman and Nugoglu (2010) also found out that the conceptions of the NOS held by male science teachers were statistically not significant in comparison to those held by female science teachers. In terms of the influence of science teachers' academic qualifications, contrary to common sense, there is no significant relationship between science teachers' academic qualifications and their conceptions of the NOS (Mellado, 1997). In fact, sometimes the relationship between academic qualification and NOS conceptions may be unexpected. In a study conducted by Dogan and Abd-El-Khalick (2008), Turkish science teachers holding master's degrees expressed more naive views than those holding bachelor's degrees, while those holding PhDs had the most misinformed conceptions. A similar trend was also observed by Bruckermann et al. (2018) in their assessment of German pre-service biology teachers.

Recent literature on teachers' perceptions of NOS have included studies that have taken RFN as a conceptual framework (Azninda & Sunarti, 2021; Takriti et al., 2023). Aksoz (2019) explored how science teachers perceive the aims and values as well as the social-institutional categories of RFN. There was no difference among the teachers' views according to teaching experience, education level and school type. Furthermore, qualitative results showed that teachers have some naïve understanding on some social-institutional categories of science such as professional activities. Demirel et al. (2023) observed that teachers with master's or PhD degrees showed more informed views of NOS. Azninda and Sunarti (2021) examined both science teachers' and non-science teachers' views on RFN. While quantitative results showed that two groups of teachers do not significantly differ from one another, the qualitative data showed that they held different views on each category of RFN. Takriti et al. (2023) investigated 130 UAE preservice teachers' understanding of the NOS. Results obtained from the RFN 70-item questionnaire demonstrate that teachers were mostly informed about issues pertaining to the social-institutional aspects compared to aspects related to the cognitive-epistemic nature of science. Beeghly, Gao and Kruse (2024) conducted a multiple-case study investigating the changes in three secondary science preservice teachers' views of the NOS using RFN. Their findings showed that there was an overall improvement in preservice teachers' views of NOS across all RFN categories, but one preservice teacher continued to hold misconceptions about scientific theories and laws after the course.

In the rest of the paper, we present an empirical study conducted with Turkish physics, chemistry and biology teachers to trace their perceptions of NOS using the RFN framework. The study contributes to the literature of science teachers' perceptions of NOS particularly to the emerging literature that has used RFN as a conceptual framework. In the empirical study, we focus on some factors in teachers such as gender and educational level of the science teachers. Although these factors have previously been investigated, they have not been framed from the point of view of the subject-matter variation of the teachers. Furthermore, we also trace how the teachers themselves view different domains of science in discussing aspects of NOS. In this sense, the paper provides a contribution to the literature by bringing to the foreground domain-specific aspects of NOS in relation to teachers' subject matter expertise. The RFN framework was chosen because it inherently utilises the domain-specificity theme that are targeted by the research questions. In other words, the foundation of RFN is about what makes different domains of science ‘science’ and how all sciences can be justified as belonging to the same endeavour while also maintaining differences. Given our interest in tracing different science subject teachers’ perceptions of NOS with respect to their own subject and other subjects, RFN provides consistency between the theoretical rationalisation of the study, the research questions and the analytical framework used in interpretation of the data.

Methodology

Research questions

The overall research question guiding the study is the following:

How do physics, chemistry and biology teachers’ perceptions of NOS compare?

In order to detail and elaborate on this research question, we posed two sub-questions as follows:

> (1) What factors influence physics, chemistry and biology teachers’ perceptions of NOS?
>
> (2) How do physics, chemistry and biology teachers view the similarities and differences among different domains of science?

Research question 1 was investigated using quantitative methods while Research question 2 was addressed through qualitative methods. While the first research question unpacks the variation between the teachers’ general demographic characteristics such as gender and educational level, the second question focuses more directly on teachers’ perceptions of NOS. Taken together, the two research questions provide a broad and comprehensive account with the potential to pinpoint different factors influencing teachers’ NOS perceptions. Previous research (e.g., Karaman, 2017) investigated aspects of teachers’ NOS perceptions such as teaching discipline, gender, educational level and teaching experience, highlighting that the variable, 'teaching discipline', had a statistically significant multivariate effect on the overall NOS conceptions of the participant teachers. Hence, the demographic factors were considered so as to be able to contextualise the current study’s findings within the existing literature.

Participants

A total of 68 teachers from different fields of science (24 biology teachers, 23 physics teachers, and 21 chemistry teachers) who were selected by convenience sampling method (Fraenkel et al., 2012) participated voluntarily in this study. There were 51 females and 17 males. In terms of the participants’ educational background, 36 had undergraduate and 32 had graduate degrees. Detailed demographic information is provided in Table 2. Using convenience sampling, the high school teachers from Turkey were accessed through an announcement in the platforms including social media and teacher forums. The biology, physics, and chemistry teachers who were available and willing to participate in the study replied that they would like to join the study. In order to reduce sample bias during selection of the participants, they were recruited by using different means such as social media, online teacher forums and email distribution lists. Hence, multiple sample sources were utilised in order to minimise sampling bias. The teachers were informed about the study and their consent was taken. Demographic information of the teachers such as gender, education level and teaching experience was collected.

Data Sources

Quantitative Data

In order to determine physics, chemistry and biology teachers' NOS perceptions in Turkey the "RFN Questionnaire" which was developed by Kaya et al. (2019) was used with the teachers. This questionnaire consists of 70 items which reflect the 5 RFN categories including aims and values, scientific values, scientific methods, scientific knowledge, and social-institutional aspects, and also educational applications (See Table 1). The questionnaire is a 5-Likert type scale consisting of the options of *'totally agree'*, *'agree'*, *'not sure'*, *'disagree'*, *and 'totally disagree'*. The Cronbach alpha value of this questionnaire is 0.8 (Kaya *et al*. 2019).

Insert Table 1 in here

Qualitative Data

In order to investigate physics, chemistry and biology teachers' views about domain specificity issue 2 open-ended questions were posed. In other words, the open-ended questions directly addressed the second research question: *How do physics, chemistry and biology teachers view the similarities and differences among different domains of science?* Thus, the purpose of the open-ended questions was to elicit teachers' perceptions of common and different features of NOS. The first question asked whether the teachers thought different fields of science such as physics, chemistry and biology have common features. The teachers were asked to explain these common features if they thought different fields have common features. In the second question, they were asked whether they thought different fields of science such as physics, chemistry and biology have features that differentiate them from each other. They were also asked to explain the domain-specific features of these disciplines, if their answer is yes. For the content validity of the questions, a pilot study was carried out with 3 teachers (1 teacher for each field) in order to check whether the teachers could understand the questions. The pilot study showed that the questions were understood by the teachers. The teachers referred to different aspects of NOS, for example scientific methods and knowledge, and some of the terminology contained in their sentences, such as words including 'experiment' and 'accuracy' suggested reference to RFN categories.

Data Analysis

The data gathered through the questionnaire were analysed by descriptive and inferential statistical analysis. These data relate to the first research question. In order to calculate the teachers' scores from the questionnaire, first, their 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. Likert scale data can be considered as interval data so that it can be used for statistical calculations (Pallant, 2005). After recoding, scores for each RFN category and for the educational applications category were calculated. Then the total score for the questionnaire was calculated by summing all the scores for 5 RFN categories and educational applications category. After calculating total scores and the scores for each category, descriptive statistics such as minimum, maximum, mean, and standard deviation (SD) values were calculated by using SPSS. These statistics were found by considering teachers' demographic information including gender and educational level, and also their fields of science. In order to explore whether there is a significant difference among teachers' NOS scores with respect to their gender, education level, and teaching experience, ANOVA as an inferential statistics analysis was run for their NOS total scores. To explore whether there is a significant difference among teachers' NOS total scores and each category scores with respect to their fields of science, again ANOVA was used. Before running ANOVAs, the equal variances assumption was checked.

In order to examine the teachers' views about the similarities and differences among different fields of science, the data gathered through the 2 open ended questions were analysed by thematic analysis as a qualitative method. This analysis addresses the second research question. In the first question of the interview, the teachers were asked whether they thought different fields of science such as physics, chemistry and biology have common features, and they were asked to explain these common features if they thought different fields have common features. In the second question, they were asked whether they thought different fields of science such as physics, chemistry and biology have features that differentiate them from each other. They were also asked to explain the domain-specific features of these disciplines, if their answer is yes. While analysing the data gathered through these questions, first the number of the teachers who wrote 'yes' and 'no' for each question was determined. Subsequently, what the teachers wrote about the common features and differences were identified by using a keyword search based on the methodology reported in Kaya and Erduran (2016).

As a first step, each teacher's response was analysed at the level of a sentence, and the keywords were traced. If a teacher's response included words such as 'accuracy', the sentence was coded as an instance of "aims and values" which is part of the cognitive-epistemic aspects of RFN. If a teacher referred to the words 'experiment' or 'observation' as a similarity or difference among different fields of science in his/her answer, this was considered as an instance of "scientific practices". For instance, in the case of the following example, the sentence was coded as an instance of "scientific methods" because there is an explicit reference to the word 'methods'.

> *"The common feature is that the steps followed in scientific research methods are the same."*

In some responses, a series of sentences written by one teacher contained several keywords that could be assigned to several RFN categories. For example, consider the following statement.

> *"Yes. Even if they are different areas, the scientific process steps such as to collect data, to organise data, to classify data, and to analyse these data are common. In addition, whatever fields the scientists work in, they are required to have common features on some aims and values as well."*

Here, the use of the words 'steps' and 'process' would suggest reference to "scientific methods" based on Kaya and Erduran's (2016) approach. Furthermore, the words 'classify data' would suggest "scientific practices" and "aims and values" would suggest the RFN category of "aims and values". In such cases where one teacher's response included several

RFN categories at once, we took note of these instances per teacher. For the intercoder reliability, two researchers coded the sentences using the keywords independently and then met to discuss the results. Any disagreements were resolved through discussion. The intercoder reliability was determined to be 0.9.

As a second step, in order to identify the perceptions of teachers from different domains, we calculated frequency counts of teachers per RFN category. The intention here was not to summarise frequencies of the categories for each teacher but rather to trace instances of occurrence of that category per teacher in a particular science domain. In other words, as an example, a physics teacher may have referred to scientific practices in conjunction with "aims and values". Here, this teacher's sentence would be counted as an instance of the mentioned categories once. If the teacher mentioned "scientific practices" several times, this result would still be counted once as an instance of occurrence of "scientific practice". The same teacher may have been counted several times across different categories. Our interest in this approach to coding was not about how many times a teacher referred to a category but rather if they referred to it or not. This is because we were interested in the distribution of teachers' perceptions of RFN categories by subject domain so that we could compare the similarities and differences across the subjects. For this purpose, the frequency counts were not essential on an individual teacher level. Future studies may explore further levels of analysis to disentangle more detailed relations between specific teachers' perceptions of RFN categories across subject domains. In the next section, we report the results of both quantitative and qualitative analyses.

Results and Findings

Quantitative Results

The descriptive statistics related to the teachers' NOS scores (each NOS category scores and total NOS scores) were calculated through SPSS. The descriptive statistics such as minimum (min), maximum (max), mean, and standard deviation (SD with respect to teachers' demographic information and their fields are presented in Table 2 and Table 3, respectively.

Insert Table 2 in here

Insert Table 3 in here

In order to explore whether there is a significant difference among teachers' NOS scores with respect to their gender, education level, and teaching experience ANOVA as an inferential statistics analysis was run for their NOS total scores. Before the analysis, the equal variances assumption was checked. Levene's Test of Equality results for each variable show that the variances of the teachers' scores are equal (See Table 4).

Insert Table 4 in here

The ANOVA results show that there was no significant mean difference between female and male teachers' perception of NOS (F (1, 66) = 2.072, p> .05). There was no significant mean difference among teachers' NOS perceptions with different education level (undergraduate, graduate) (F (1, 66) = .009, p> .05). There was no significant mean difference among teachers' NOS perceptions with different teaching experience (0-5 years, 6-10 years, 11-15 years, and more than 15 years) (F (3, 64) = 1.169, p> .05).

In order to explore whether there is a significant difference among physics, chemistry and biology teachers' NOS perceptions, ANOVA as an inferential statistics analysis was run for their scores of each category as well as their total scores. For the equal variances assumption, Levene's Test of Equality result (F (2, 65 = .339, p>.05) shows that the variances of the teachers from 3 fields are equal (See Table 5).

Insert Table 5 in here

The ANOVA results for total NOS scores show that there was no significant mean difference among physics, chemistry and biology teachers' perception of NOS (F (2, 65) = 2.366, p> .05). The ANOVA results for each NOS category show that there was no significant mean difference among physics, chemistry and biology teachers' perception of aims and values (F (2, 65) = 2.449, p> .05), scientific practices (F (2, 65) = .465, p> .05), methods (F (2, 65) = 3.150, p> .05), social-institutional aspects (F (2, 65) = 1.499, p> .05), and educational applications (F (2, 65) = 1.103, p> .05). However, the results show that there was a significant difference among physics, chemistry and biology teachers' perception of scientific knowledge (F (2, 65) = 6.617, p< .05) in favour of physics teachers. The physics teachers' SK mean score (35.44) are higher than both chemistry teachers' SK mean score (32.76) and biology teachers' SK mean score (33.04) (See Table 3).

Qualitative Results

The main objective of the qualitative analysis was to have a comparison of the similarities and differences between the physics, chemistry and biology teachers. Hence, in the rest of this section we organise the results in relation to similarities and differences among the subject teachers. First, we report about the teachers' perceptions of the similarities among different domains of science and subsequently, we focus on the differences. Furthermore, as a second level of organisation, for each similarity and difference, we trace the RFN category in the sequence reported in the literature background.

Teachers' perceptions of similarities among different domains of science

The physics, chemistry and biology teachers were asked whether they thought different fields of science such as physics, chemistry and biology have common features. They were also asked to explain what these common features might be if their answer is yes. The teachers mainly focused on content, and cognitive-epistemic aspects of science (i.e. aims and values, methods, scientific practices, and scientific knowledge) as the common features of physics, chemistry and biology. By 'content', we mean "subject knowledge" as described previously in the introduction section in relation to Shulman's (1986) definition. When we refer to "scientific knowledge" in the context of RFN, however, we refer to a NOS category in relation to the nature of theories, laws and models as described by Erduran and Dagher (2014). As common features, the teachers only made reference to themes related to social values and scientific ethos as part of the social-institutional aspects.

Eight teachers out of 24 biology teachers, 6 teachers out of 23 physics teachers, and 6 teachers out of 21 chemistry teachers referred to content as the common feature. These teachers think that physics, chemistry and biology make a contribution to explain a topic by supporting each other. Some teachers also link the common content to interdisciplinarity of these fields. For example, the answers of some teachers from three fields are given below:

> *"Yes, of course. They all are all interrelated. Chemistry and biology are nested. The accuracy of one is structured with the other's support. For example, to link the reasoning about veins in biology with gravity in physics), to support the formula of a glucose with chemistry." (B-53)*

> *"We see that there is a big bond between physics and chemistry. For example, models of atoms, energy, heat and temperature, quantum physics. We can say the same for physics and biology as well. For example, energy, motion, and pressure." (P-6)*

> *"Yes, for instance, I need to refer to the fields of biology and physics while I am teaching chemistry which is my field. The topics of force, radioactivity, sub-atomic particles, motion, electricity, etc., in physics. Nucleic acids, proteins, carbohydrates, and lipids. The minerals that are necessary for human health." (C-19)*

Furthermore, there was explicit reference to interdisciplinarity in some teachers' responses as follows including reference to STEAM (Science-Technology, Engineering-Arts-Mathematics):

> *"The subjects and concepts in science might be related to other disciplines. Therefore, interdisciplinary collaboration is important. For example, we have to use probability in mathematics while teaching heredity in biology." (B-44)*

> *"Yes, there are formulas and laws in the three fields, and some scientific studies are common in these fields." (C-8)*

> *"There is commonality in laboratory use. In addition, some common studies can be conducted in the projects such as STEAM." (P-31)*

The teachers from three fields also focused on aims and values of science as a common feature that physics, chemistry and biology have. Their answers show that they perceive that the common feature of these fields are their aims such as to explain nature, to understand nature, accuracy, consistency, rationality, and testability. Seven biology teachers, 2 physics teachers, and 5 chemistry teachers referred to aims of the fields as the common feature. For example, a biology teacher stated that:

> *"Yes. Some values and aims that drive the scientific enterprise overlap. These are accuracy, consistency, scepticism, rationality, etc. Some applications like observation, experiment, and classification are used." (B-60)*

Similarly, a physics teacher wrote that:

> *"Yes. As a result, nothing is independent. For example, understanding how the universe is formed, understanding matter, energy and basic forces would help us to understand life as we know it. Same thing for chemistry." (P-5).*

In her answer, a chemistry teacher focused on aims of science and content of three fields as their common features:

> *"Chemistry was born out of the needs of humans. Science was born out of understanding nature, and it is shaped by needs. The sub-fields are divided based on content but the starting point of all is common. Chemistry establishes commonality with physics through the topic of energy and with*

> *biology through biochemistry topics. While chemistry makes batteries, physics deals with how a battery is used in the most efficient way." (C-52)*

The other common feature of three fields that the teachers emphasised is methods used in physics, chemistry and biology. Five biology teachers, 4 physics teachers, and 7 chemistry teachers referred to methods as the common feature. The teachers thought that the steps followed in conducting a study in physics, chemistry and biology are the same. They actually refer to a "step by step" method including asking questions, constructing a hypothesis, collecting data, and analysing data. Some examples of the answers of teachers from three fields are presented below:

> *"The common feature is that the steps followed in scientific research methods are the same." (B-54)*
>
> *"Yes. To have the processes of writing down research questions, producing a testable answer for this question (hypothesis), collecting data, evaluating data, and suggesting method, design etc. for future research are the common features of the fields of physics, chemistry, and biology." (P-34)*
>
> *"Yes. Even if they are different areas, the scientific process steps such as to collect data, to organise data, to classify data, and to analyse these data are common. In addition, whatever fields the scientists work in, they are required to have common features on some aims and values as well." (C- 4)*

The teachers also pointed out some scientific practices as another common feature that three fields have. Five biology teachers, 2 physics teachers, and 1 chemistry teacher referred to practices used in different fields as the common feature. They thought that each field uses experiment and observation. One biology teacher also referred to classification in addition to experiment and observation as common practices used in the three fields. Her answer including these scientific practices and aims and values is given below:

> *"Yes. Some values and aims that drive the scientific enterprise overlap. These are accuracy, consistency, scepticism, rationality, etc. Some applications like observation, experiment, and classification are used." (B-60)*

Two biology teachers, 2 physics teachers, and 3 chemistry teachers perceive scientific knowledge as a common feature of three fields. These teachers did refer to theories, laws, and models as types of scientific knowledge in their answers. Some examples from different fields are given below:

> *"All of them try to explain natural events, matters and their interactions, develop models and theories. Their research methods are similar. Chemistry conducts joint studies with both fields of science." (C-12)*
>
> *"Yes, all three fields are basic sciences and contribute to technology by producing scientific knowledge." (B-13)*
>
> *"The laws of nature do not change. The entropy example is valid for each field of science." (P-10)*

In terms of social-institutional aspects of science, the teachers from three domains emphasise only social values and scientific ethos. 2 physics and 2 chemistry teachers referred to only serving humanity which is coded as social values and only one biology teacher referred to being sceptical which is coded as scientific ethos. Some examples are given below:

> *"There is humanity at the core of science. All three fields exist for serving humanity." (C-66)*
>
> *"Of course yes, all three sciences can make an effort for people to live a more prosperous life in a cleaner environment. The opposite is possible as well. They can all make life unbearable for people by producing chemical and biological weapons so that they would have problems living peacefully. This is also a common feature." (P-25)*

In addition, while one physics teacher and two biology teachers think that physics, chemistry and biology do not have any common features, there is not any chemistry teacher who thinks as such. In order to explore their views of the differences among the three domains of science, the physics, chemistry and biology teachers were asked whether or not they thought different domains have features that differentiate them. They were also asked to explain what the domain specific features of these disciplines might be if their answer is yes. The teachers mainly focused on content, and cognitive-epistemic aspects of science as the features that differentiates physics, chemistry and biology as the common feature. However, they did not refer to any social-institutional aspects of science as a difference.

Teachers' perceptions of differences among different domains of science

Fifteen teachers out of 24 biology teachers, 10 teachers out of 23 physics teachers, and 12 teachers out of 21 chemistry teachers in each field focused on the content of physics, chemistry and biology as the feature that differentiates them from each other. Some examples of teachers' answers which refer to the content of the fields are given below:

> *"Biology is a field of science that examines the science of cells. It is responsible for everything that involves living things. Physics includes research studies aiming to understand how the universe works. Chemistry is a field of science that examines the structure, mechanism, and interaction of matter." (B-54)*
>
> *"Physics examines mostly matter-energy interactions, chemistry examines chemical changes and reactions, and biology examines the science of cells." (P-14)*
>
> *"For example, while chemistry is more interested in the inner structure of matter and their transformation to each other, physics is more interested in the motion of matter and the results of this motion. Biology examines these concepts in relation to living things." (C-19)*

Among biology teachers, in addition to content of fields as a difference, 2 teachers point out scientific knowledge and 2 teachers point out aims of science. For example, as it is given below, one biology teacher’s answer reflects that she thinks that knowledge in biology is tentative but knowledge in physics and chemistry is not:

> *“Biology is a living science which can be changed more with new discoveries. We can mention acceptance and certainty for physics and chemistry. The new discoveries in physics and chemistry can give a deeper detail for that knowledge but everything can lose its validity in biology.” (B-49)*

One biology teacher thinks that physics differs from biology and chemistry since theories and laws in physics are different from those in biology and chemistry.

> *"I think that physics is different from chemistry and biology. In my opinion, the theories and laws in physics are independent from those in biology and chemistry. (B-55)*

Another biology teacher refers to understanding different categories of nature as the difference among three fields which can be coded as aims of science. Among physics teachers, 2 teachers point out methods and 2 teachers point out scientific knowledge as the difference among the fields. They think that physics is mainly based on theoretical research while biology and chemistry are mainly based on experimental or empirical research. These teachers’ answers are given below:

> *“Yes. I think that theoretical studies in physics come into prominence when compared to other fields of science.” (P-51)*
>
> *“I do not know much about this. But while the experimental studies can be conducted in especially chemistry and biology, theoretical and empirical studies can be conducted in physics.” (P-2)*

One physics teacher emphasises scientific knowledge as the difference among the fields:

> *“Yes, the laws and knowledge in physics can make clear the events related to biology and chemistry.” (P-25)*

While there are 3 biology and 4 chemistry teachers who think that the fields of science do not differ, there is only one physics teacher who thinks this. Moreover, 2 physics teachers maintain the perception that physics is the core science as compared to biology and chemistry. The examples of these perceptions are given through the following statements:

> *“I think that chemistry and biology are subfields of physics rather than being different fields. At the outset, all living and nonliving matters around us can be reduced to sub-atomic particles. This is the research area of particle physics.” (P-34)*
>
> *“Physics is the foundation of science” (P-36)*

Among chemistry teachers, 2 teachers point out scientific practices and 1 teacher points out scientific knowledge as the difference. For example, the following answer shows that this chemistry teacher perceives the practices used in these fields as the difference. She emphasises classification in biology and experiment in physics and chemistry:

> *"Yes, for example most of the experimental studies in the field of biology are related to physics/chemistry but the classification studies are specific to biology itself." (C-23)*

One chemistry teacher thinks that each field has its own symbolic language, experimental practice, research field, and perspective. She emphasises the importance of the nature of each field even if examining a common topic. Thus, this teacher's views reflect scientific practices, content, and the nature of domain:

> *"Each field has its own symbolic language, experimental practice, research area, and perspective. The fields of science act based on each one's own nature even if they examine a common event." (C-27)*

Overall, the findings illustrate how physics, chemistry and biology teachers view their own subject as well as other science domains. They provide insight into how teachers of different science subjects view the cognitive-epistemic and social-institutional aspects of their own domain that they teach as well as those of other science domains.

Conclusions & Discussion

When the results from the qualitative data analysis are contrasted with those from quantitative data analysis, various observations can be noted. Although the teachers' gender, teaching experience and educational level do not contribute to any variation in their perceptions of NOS, their subject-matter specialisms influence how they view different aspects of NOS. This observation is corroborated through some of the findings from the qualitative data analysis which provides detailed variations among the teachers indicating a complex set of relations between the similarities and differences across subject specialism. For example, for the scientific practices category, the quantitative results do not point to any significant variation among the physics, chemistry and biology teachers while the qualitative results point to an emphasis on classification as scientific practice being mentioned by more biology teachers than chemistry and physics teachers.

The findings further illustrate how physics, chemistry and biology teachers view their own subject as well as other science domains. Some of the findings resonate with traditional hierarchies that have been about scientific knowledge and methodology. For example, there was a traditional assumption that sciences are arranged in a hierarchy, with developed natural sciences like physics at the top and social sciences like sociology at the bottom (Cole, 1983). The teachers' references to the quality of knowledge generated in physics versus biology, for instance, resonate with such views of scientific knowledge. Similarly, the myth of the scientific methods as being a linear, step-by-step process (McComas, 1996) is prevalent in this cohort of teachers' perceptions.

The paper presented an investigation of science teachers' NOS perceptions in relation to different aspects of NOS and presented a comparison of the role of the subject knowledge background of the teachers. The study presented in the paper is in line with a body of research that has taken domain-specificity as a focal point for investigating different subject teachers' views of NOS. For example, Veal & Kubasco (2003) discussed how biology versus geology teachers view the teaching of evolution, revealing epistemological differences between disciplines. Consistent with existing research (e.g., Mellado, 2007; Yaman and Nugoglu, 2010), no effects were found about gender, teaching experience and educational level. Overall, based on the quantitative analysis, findings suggest that there are no statistically significant differences among the teachers' views of NOS across different categories of RFN except for the scientific knowledge category. The physics teachers' scores of scientific knowledge are higher than those of biology and chemistry teachers'.

However, closer examination of data illustrates that all teachers emphasise scientific knowledge as a key feature in domain-specificity. Physicists stress variations across domains in relation to scientific methods to a greater expert while chemists do so in relation to scientific practices and biologists in relation to aims and values of science. In other words, different subject teachers have highlighted domain-specificity of NOS in relation to different RFN categories suggesting that particular science subject teachers might have propensity to emphasise different aspects of NOS when presented with a holistic account of NOS. Furthermore, teachers' interdisciplinary views of NOS suggest their potential in understanding domain-specific as well as domain-general features of NOS. In other words, teachers could speak to the particular features of their own subject as well as common features of all science subjects. The teachers made links across the domains at the level of subject matter content, on observation suggesting that teachers are able to engage in deep thinking about their subject matter.

Previous research on science teachers' perceptions of NOS have focused on some of the particular epistemological themes in relation to scientific knowledge, such as the distinction between theories, laws and hypotheses (e.g., Abd-El-Khalick, 2008; Akerson et al., 2006; Aslan & Taser, 2013) as well as the scientific method (e.g., Mesci & Schwartz, 2017). The findings of the current study in relation to teachers' perceptions of scientific knowledge and methods are consistent with such previously published research. For example, the teachers' reference to a step-by-step method in science is consistent with the myth of the scientific method (McComas, 1996). However, the details of some of the RFN categories provide further nuance to under investigated aspects of NOS, for example, when a biology teacher referred to classification as a scientific practice in addition to experiment and observation. Classification as scientific practice has not been an explicit part of previous NOS frameworks in the way that it is captured within the RFN framework.

Furthermore, by using the RFN framework, we have brought together the various aspects of NOS, ranging from the cognitive-epistemic to social-institutional dimensions to investigate any potential variation among teachers of physics, chemistry and biology. Other studies have explored the personal and social aspects of science including the role of creativity in science and how teachers view such aspects of science (Akerson & Donnelley, 2008). The social-institutional RFN categories provide specificity of aspects such as the political power structures and financial systems in ways that previous literature had not taken into account in teachers' NOS perceptions. The qualitative data provide rich information about how teachers view different domains of science when discussing aspects of NOS. In this sense, the paper provides a contribution to the literature by bringing to the foreground domain-specific aspects of NOS in relation to teachers' subject matter expertise.

The study suggests teachers are likely to emphasise different aspects of NOS based on the scientific discipline that they teach. For example, physicists highlighting scientific knowledge aspects versus biologists stressing aims and values aspects. Such variations may potentially result in students developing analogous perceptions of the subject that is being taught. However, such possibilities demand further empirical studies to ascertain how teachers' perceptions and teaching practices may or may not correlate. Although a balanced and equivalent coverage of the RFN categories across all science subjects may be idealised and unrealistic, it will be beneficial for different subject teachers to be aware of which aspects of NOS they tend to emphasise, why and when. For example in some science lessons, an overemphasis on one aspect may be called for depending on the curricular objectives, while in others such emphasis may not be helpful as they may imply an arbitrary specification about the science domain as though that aspect is more important for that domain.

The study has implications in science education including from the perspective of RFN applications in science teachers' professional development (e.g., Barak, Yachin & Erduran, 2023) and the content of the science curriculum (e.g., Kaya, Erduran & Okan, 2024) in relation to domain-specific approaches to NOS. Highlighting the domain-specific as well as the domain-general aspects of NOS is critical for developing science teachers' awareness of their own subject's particular features as well as those aspects of their subject that are similar to other domains of science. If such distinctions are not explicitly made in teachers' learning and in science curricula, there will be many missed opportunities eventually for learners of science to understand what characterises a particular domain 'science' and how different fields of scientific inquiry relate to each other in terms of their similarities and differences.

For example, one of the chemistry teachers in the study viewed classification as a specific practice in biology, not recognising that it can also relate to physics and chemistry. The teacher stated that *"most of the experimental studies in the field of biology are related to physics/chemistry but the classification studies are specific to biology itself."* Here there is a missed opportunity in recognising that while classification can be a domain-general practice in science, it will have particularities in a domain-specific manner in all of physics, chemistry and biology. Extended discussions about such contrasts of domain-general and domain-specific RFN categories can potentially help both teachers and students in understanding nuances across domains of science and more broadly NOS itself. This perspective is consistent with the theoretical orientation presented within the RFN framework as the framework emphasises the significance of understanding NOS in a nuanced manner where even a scientific practice can be both a similarity and a difference across domains. Finally, future research can extend the methodological approaches utilised in this paper to include for example, in-depth interviews to explicate further the nuances across the subject teachers' views of NOS in relation to domain-specificity.

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Table 1 Positive and negative items in the RFN Questionnaire (from Kaya et. al, 2019, p. 30)

Category	Example	Number of items dedicated to RFN category	Item reference in questionnaire	
			Positive	Negative
Aims and values	*The diversity of scientists solving a problem means less biased results* (Positive item)	7	2, 20, 40, 51, 69	46, 56
Scientific practices	*Each branch of science has a different nature* (Positive item)	13	4, 5, 15, 19, 23, 33, 38, 57, 61, 63	26, 52, 64
Scientific methods	*All scientific disciplines such as physics, biology and chemistry use the same scientific method* (Negative item)	9	11, 22, 24, 28	8, 25, 37, 49, 60
Scientific knowledge	*Scientific knowledge does not change* (Negative item)	9	10, 30, 44, 50, 54	3, 16, 43, 66
Social-institutional aspects	*Scientists should respect the environment* (Positive item)	16	7, 9, 14, 32, 34, 41, 45, 48, 53, 58, 67, 70	13, 18, 36, 39
Educational aspects	*Teaching science should specify that laws are certain and unchangeable.* (Negative item)	16	1, 6, 12, 17, 21, 27, 29, 31, 42, 55, 59, 62, 65	35, 47, 68

Table 2 Descriptive Statistics of NOS scores based on teachers’ demographic information

Descriptive Statistics						
Variable	Group	N	Min	Max	Mean	SD
Gender	Female	51	241.00	296.00	271.45	11.65
	Male	17	256.00	310.00	276.53	15.17
Education Level	Undergraduate	36	241.00	310.00	272.86	13.55
	Graduate	32	253.00	300.00	272.56	11.88
Teaching Experience	0-5 years	8	262.00	300.00	277.38	12.25
	6-10 years	16	249.00	279.00	268.06	8.92
	11-15 years	11	257.00	295.00	274.36	12.64
	More than 15 years	33	241.00	310.00	273.30	14.14

Table 3 Descriptive Statistics of NOS total scores and NOS category scores based on the field and whole group

Descriptive Statistics						
Group	Score	N	Min	Max	Mean	SD
Physics	NOS*	23	258	300	276.30	11.97
	AV	23	22.00	31.00	25.65	2.35
	SP	23	50.00	59.00	53.22	2.89
	M	23	20.00	36.00	28.61	4.22
	SK	23	31.00	42.00	35.44	3.42
	SI	23	57.00	74.00	65.61	4.40
	EA	23	61.00	75.00	67.78	3.86
Chemistry	NOS	21	253	291	268.19	10.42
	AV	21	19.00	30.00	26.05	3.19
	SP	21	47.00	57.00	52.38	2.58
	M	21	22.00	33.00	26.38	2.82
	SK	21	29.00	37.00	32.76	2.17
	SI	21	58.00	74.00	65.10	4.74
	EA	21	56.00	78.00	65.52	5.42
Biology	NOS	24	241.00	310	273.25	14.36
	AV	24	20.00	35.00	27.50	3.40
	SP	24	44.00	59.00	52.46	3.96
	M	24	18.00	35.00	26.25	3.49
	SK	24	29.00	39.00	33.04	2.37
	SI	24	56.00	80.00	67.50	5.61
	EA	24	54.00	78.00	66.50	5.73
Whole Group	NOS	68	241.00	310.00	272.72	12.70
	AV	68	19.00	35.00	26.43	3.08
	SP	68	44.00	59.00	52.69	3.20
	M	68	18.00	36.00	27.09	3.69
	SK	68	29.00	42.00	33.77	2.94

	SI	68	56.00	80.00	66.12	5.00
	EA	68	54.00	78.00	66.63	5.08

*NOS: Nature of Science, AV: Aims and Values, SP: Scientific Practices, M: Methods, SK: Scientific Knowledge, SI: Social-Institutional System, EA: Educational Applications

Table 4 Test of Homogeneity of Variances for teachers' NOS total scores and NOS category scores in terms of different variables

Variable	**Levene Statistic**	**df1**	**df2**	**Sig.**
Gender	2.699	1	66	.105
Education Level	.005	1	66	.944
Teaching Experience	1.313	3	64	.278

Table 5 Test of Homogeneity of Variances for teachers' total NOS scores in terms of their fields

Score	**Levene Statistic**	**df1**	**df2**	**Sig.**
NOS*	.339	2	65	.713
AV	1.067	2	65	.350
SP	2.651	2	65	.078
M	2.160	2	65	.123
SK	2.937	2	65	.060
SI	.674	2	65	.513
EA	1.357	2	65	.265

*NOS: Nature of Science, AV: Aims and Values, SP: Scientific Practices, M: Methods, SK: Scientific Knowledge, SI: Social-Institutional System, EA: Educational Applications