THE IMPACT OF AN ONLINE COLLABORATIVE AND REFLECTIVE PROFESSIONAL DEVELOPMENT PROGRAM ON SCIENCE TEACHERS' PERCEPTIONS ABOUT THE NATURE OF SCIENCE AND INSTRUCTIONAL PRACTICES

by

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To the flowers that remind me of beauty and hope, and to my beloved cat, Safiş,
whose presence brought warmth and calm to every step of the journey

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ABSTRACT

THE IMPACT OF AN ONLINE COLLABORATIVE AND REFLECTIVE PROFESSIONAL DEVELOPMENT PROGRAM ON SCIENCE TEACHERS' PERCEPTIONS ABOUT THE NATURE OF SCIENCE AND INSTRUCTIONAL PRACTICES

This study examines the effects of a teacher professional development (PD) program on science teachers' nature of science (NOS) perception, their instructional practices, and their reflections on collaborative work, learning, and teaching NOS. The theoretical background of the study is Erduran and Dagher's (2014) Reconceptualized Family Resemblance Approach (FRA) to NOS, which has later been termed "RFN" by Kaya and Erduran (2016). The RFN framework encompasses cognitive, epistemic, and social-institutional aspects of science, offering pedagogical strategies and practical applications for science education settings. A multiple case study design was employed. The online PD program, spanning nine weeks with pre- and post-data collection, included three sessions for each workshop: (1) developing theoretical knowledge related to RFN categories through collaborative activities, (2) designing lesson plans in groups, and (3) reflecting on and discussing the implementation of lesson plans. Six science teachers from Istanbul participated in the study. Diverse data sources were used, including pre- and post-visual representations, pre- and post-individual interviews, lesson plans, observation forms, weekly teacher journals, and group discussions. Reflective Drawing Analysis (Barak *et al.*, 2023) was applied to the visual representation data, while qualitative analysis was used for the other data sources. The results indicated that science teachers developed a more sophisticated understanding of RFN categories following the PD program. Teachers effectively translated their NOS understanding into instructional practices, successfully integrating NOS into their lesson plans and teaching. Their reflection on the online collaborative and reflective nature of the online PD program was positive. The study has significant implications for teacher education programs, the design of PD programs, curriculum development, and future research.

ÖZET

ÇEVRİMİÇİ İŞBİRLİKÇİ VE YANSITICI MESLEKİ GELİŞİM PROGRAMININ FEN BİLİMLERİ ÖĞRETMENLERİNİN BİLİMİN DOĞASI ANLAYIŞLARI VE ÖĞRETİM UYGULAMALARI ÜZERİNE ETKİSİ

Bu çalışma, bir öğretmen mesleki gelişim (PD) programının fen bilimleri öğretmenlerinin bilim doğası (NOS) algıları, öğretim uygulamaları ve NOS'un işbirlikçi çalışması, öğrenimi ve öğretimi üzerine yansımaları üzerindeki etkilerini incelemektedir. Çalışmanın teorik temeli, Erduran ve Dagher'in (2014) Bilim Doğasına Yönelik Aile Benzerliği Yaklaşımı'na (FRA) dayanmaktadır; bu yaklaşım, daha sonra Kaya ve Erduran (2016) tarafından "Yeniden Kavramsallaştırılmış Aile Benzerliği Yaklaşımı" (RFN) olarak adlandırılmıştır. RFN çerçevesi, bilimin bilişsel, epistemik ve sosyo-kurumsal yönlerini kapsar ve fen eğitimi ortamları için pedagojik stratejiler ile pratik uygulamalar sunar. Çalışmada çoklu vaka çalışması tasarımı kullanılmıştır. Dokuz hafta süren ve öncesi ve sonrası veri toplama süreçlerini içeren çevrimiçi PD programı, her hafta üç oturumdan oluşmuştur: (1) RFN kategorilerine ilişkin teorik bilginin işbirlikçi etkinliklerle geliştirilmesi, (2) gruplar halinde ders planı tasarımı ve (3) ders planlarının uygulanmasına yönelik yansıtma ve tartışma. İstanbul'dan altı fen bilimleri öğretmeni çalışmaya katılmıştır. Çalışma öncesi ve sonrası görsel temsiller ve bireysel görüşmeler; süreç boyunca ise ders planları, gözlem formları, haftalık öğretmen günlükleri ve grup tartışmaları gibi çeşitli veri kaynakları kullanılmıştır. Görsel temsil verileri için Yansıtıcı Çizim Analizi (Barak *et al.*, 2023) uygulanırken, diğer veri kaynakları için nitel analiz yöntemi kullanılmıştır. Sonuçlar, fen bilimleri öğretmenlerinin PD programı sonrasında RFN kategorilerine dair daha derin bir anlayış geliştirdiğini göstermiştir. Öğretmenler, NOS anlayışlarını öğretim uygulamalarına etkili bir şekilde aktarmış ve NOS'u ders planlarına ve öğretimlerine başarılı bir şekilde entegre etmiştir. Çevrimiçi PD programının işbirlikçi ve yansıtıcı doğasına ilişkin yansımaları olumlu olmuştur. Bu çalışma, öğretmen eğitimi programları, PD programlarının tasarımı, müfredat geliştirme ve gelecekteki araştırmalar için önemli önerilere sahiptir.

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LIST OF ABBREVIATIONS

AV	Aims and Values
BRH	Benzene Ring Heuristics
FRA	Family Resemblance Approach
GIS	Generative Images of Science
HOS	History of Science
M	Scientific Methods and Methodological Rules
MoE	Ministry of Education
NOS	Nature of Science
PD	Professional Development
RFN	Reconceptualized Family Resemblance Approach to Nature of Science
SK	Scientific Knowledge
SP	Scientific Practices
SI	Social-Institutional Aspects of Science
TLM	Theories, Laws, and Models

1. INTRODUCTION

The nature of science (NOS), as one of the debated issues, has been studied in science education for decades (Lederman *et al.*, 2002; Erduran and Dagher, 2014; Hodson and Wong, 2017). The term "nature of science" (NOS) refers to the processes underlying science, as well as some fundamental concepts and ideas that help frame science as a method of understanding and describing the features of scientific knowledge (McComas *et al.,* 1998). Teaching NOS is viewed as one of the central components of scientific literacy, with many educational reforms emphasizing the importance of including NOS objectives in science curricula (AAAS 1990; National Research Council [NRC] 1996). It has been observed that there is also a shift from teaching science solely as facts and principles to representing it as an endeavor that highlights its limits and social aspects (McComas *et al.,* 1998; Erduran and Dagher, 2014).

Over the past two decades, studies, publications, and science instruction have largely been based on the principles of the “Consensus View” put forth by Abd-El-Khalick, Bell, and Lederman (1998). The Consensus View explains NOS through seven aspects that demonstrate researcher unanimity regarding the organization of science and how scientific knowledge is produced. It defines NOS according to seven tenets: the empirical nature of scientific knowledge, the creative character of knowledge, the distinction between theories and laws of science, the theory-laden nature of knowledge, the social and cultural aspects of research, and the myths of scientific processes (Lederman *et al.,* 2002). Numerous research studies have been conducted using these principles as their foundation in different contexts (Yakmacı, 1998; Tairab, 2001; Akerson and Abd-El-Khalick, 2003; Doğan and Abd-El-Khalick, 2008; Aslan, 2009).

On the other hand, the Consensus View received criticism from many researchers on different fronts (Clough, 2007; Allchin, 2011; Matthew, 2012; Yacoubian, 2012; Erduran and Dagher, 2014), and several alternative views were proposed (Allchin, 2011; Irzik and Nola, 2011; Matthew, 2012; Erduran and Dagher, 2014). For example, the Consensus View was criticized for being developmentally and practically inadequate (Yacoubian, 2012). Alchin (2011) put forth the "Whole Science" perspective as an alternative. Allchin focused

on the science curriculum and argued that it lacks the inclusion of controversial issues. In contrast, a set of dimensions aids students in understanding how reliability influences the development of knowledge and how science operates. Matthew (2012) preferred to use the terminology of “Features of Science (FOS)” instead of NOS to emphasize philosophical, historical, and economic considerations.

Moreover, the "Family Resemblance Approach (FRA)" was developed by Irzik and Nola (2011, 2014) as an alternative to the Consensus View, which is based on the work of Wittgenstein (1958). According to Wittgenstein's "family resemblance" theory, concepts cannot be defined solely in terms of their required conditions and essences. They illustrate the shared traits of scientific disciplines while acknowledging their diversity. Additionally, Erduran and Dagher (2014) broadened the scope of each category proposed by Irzik and Nola (2011) and offered various educational applications of FRA in science lessons. FRA provides a more holistic, flexible, and representative perspective, presenting NOS aspects as cognitive-epistemic and social-institutional systems. Each system encompasses diverse meta-level categories that are overlooked when comparing the Consensus View of the NOS. Furthermore, Erduran and Dagher (2014) added new categories, developed each category, and proposed pedagogical tools and strategies for NOS instruction in science classrooms. Thus, they reconceptualized Irzik and Nola's FRA into an NOS framework for teaching NOS in science education. Kaya and Erduran (2016) used the acronym "RFN" [Reconceptualized Family Resemblance Approach (FRA) to Nature of Science (NOS)] to differentiate it from Irzik and Nola’s (2011) framework. In the current study, the theoretical background will be based on the RFN framework.

Most studies conducted with students indicate that they generally do not have an informed understanding of NOS and also hold some misconceptions regarding the characteristics of scientific knowledge (Abd-El Khalick, 2002; Lederman, 2007). These studies have increased the focus on teachers. According to some studies, science teachers either have a poor understanding of NOS or hold incorrect beliefs about how scientific knowledge is produced (Abd-El Khalick and BouJaoude, 1997; Leden, *et al.,* 2015). Additionally, other studies have examined whether teachers’ understanding of NOS affects their instruction and practice in teaching science (Yakmacı, 1998; Akerson and Hanuscin, 2007; Aslan, 2009; Aslan and Tasar, 2013). For example, Akerson and Hanuscin (2007)

developed a professional development (PD) program to determine elementary teachers' views of NOS, their instructional practices in science lessons, and the effects of their instruction on their students' NOS views. The study found that both teachers and elementary students improved their NOS views, and teachers' science pedagogical content knowledge also developed. Considering the RFN-based studies, empirical research has mainly focused on pre-service teachers (Sarıbaş and Ceyhan, 2015; Kaya *et al.*, 2019; Erduran *et al.*, 2020; Cullinane and Erduran 2022). On the other hand, RFN-based studies regarding in-service science teachers are very limited (Aksöz, 2019; Kelly and Erduran, 2019; Azninda and Sunarti, 2021; Demirel, *et al.,* 2023; Beeghly, *et al*., 2024; Kurt and Kaya, 2024), generally aiming to investigate in-service teachers' perceptions about RFN.

When considering the studies on teachers' translation of NOS understanding into their instruction, various reasons for inadequate transmission were identified, such as insufficient emphasis on NOS in their planning, poor understanding of NOS, lack of confidence, lack of curricular emphasis, and concerns regarding the academic levels of students (Aslan and Tasar, 2013; Demirdogen *et al.,* 2016; Leden *et al.*, 2015; Aksöz, 2019). For example, Aksöz (2019), in her dissertation, also aimed to investigate teachers' suggestions for effective NOS instruction. The findings indicated that teachers need to enhance their NOS understanding and instructional strategies through effective teacher training. Most participants expressed concerns about the lack or insufficient emphasis on NOS issues in teacher education programs. Consequently, this study aimed to improve both science teachers' NOS understanding and their instructional practices.

In the context of in-service teachers' professional development in Türkiye, teacher professional development is actively supported by a diverse range of institutions, including governmental agencies, NGOs, and foundations. The main teacher trainings are administered by the General Directorate of Teacher Training and Development. Since 2005, the Ministry of National Education has emphasized the importance of participating in training sessions through the Ministry of National Education Information Systems (MEBBİS – Milli Eğitim Bakanlığı Bilişim Sistemleri). After the COVID-19 pandemic, most training has been conducted through the online platform of the Teacher Information Network (ÖBA - Öğretmen Bilişim Ağı) (MEB, 2022). ÖBA offers asynchronous training across various domains (MEB, 2022). These programs typically adopt a seminar-style format, prioritizing

broad knowledge dissemination rather than in-depth, specialized content or practical classroom applications. The lack of interaction among participants and the absence of strategies to directly influence teaching practices have made these trainings inadequate for addressing teachers' professional needs (Borko, 2004). This observation has fueled my interest in exploring alternative PD models that are collaborative, reflective, and tailored to classroom realities.

The current studies on teachers' professional development (PD) emphasize the creation of a learning community as a vital element of teacher learning (Palloff and Pratt, 2007; Vescio, *et al.,* 2008; OECD, 2014; Vangrieken *et al.,* 2017). International PD programs highlight the effectiveness of collaborative approaches, where teachers co-develop lesson plans, share classroom experiences, and engage in reflective dialogue (Vescio *et al.*, 2008; Darling-Hammond *et al.*, 2017). Being part of a community enables participants to actively contribute to their creation of knowledge and meaning, engage in collaborative activities, reflect on their practices, and become experts in their learning processes (Palloff and Pratt, 2007). An online learning community, conversely, is formed through technology and fosters collaboration and communication among teachers and experts (Rovai and Jordan, 2004; Macià and Garcia, 2016). Additionally, effective PD programs are suggested to provide active learning, collective participation, coaching, and a professional learning community (Darling-Hammond and McLaughlin, 1995; Borko *et al.,* 2010). However, studies indicate that teachers in most training sessions are not actively engaged, and their interactions are limited (İnce *et al.,* 2019; Yıldırım, 2020). Therefore, there is a need to organize PD programs that enable teachers to collaborate in a learning community, actively participate in their learning, and share their experiences through reflective activities.

As a full-time science teacher and researcher with nine years of experience, my motivation to explore the NOS in the context of teacher PD arises from both personal and professional insights. My engagement with NOS through my master's studies and related projects has highlighted its importance beyond understanding scientific concepts. NOS encompasses the cognitive, epistemic, and social-institutional dimensions of science, shaping how individuals perceive scientific processes and their societal implications (Erduran and Dagher, 2014). For instance, reflecting on natural phenomena like earthquakes in Türkiye, I noticed that individuals' scientific reasoning, such as analyzing causes, effects,

or mitigation strategies, is closely tied to their understanding of NOS. A solid grasp of NOS fosters a more rational, innovative, and inquiry-driven society, capable of critically engaging with real-world issues (Lederman and Lederman, 2014). As teachers play a pivotal role in shaping future generations' perspectives, enhancing their understanding of NOS is not only a professional goal but also a societal responsibility.

In this context, this study focuses on enhancing science teachers' understanding of NOS and improving their instructional strategies for teaching NOS through an online reflective and collaborative PD program based on the RFN framework.

1.1. Significance of the Study

This study may have several contributions to science education research concerning the professional development of teachers in the context of NOS teaching and learning, along with some methodological innovations.

Although teaching and learning NOS is a debated issue in science education research, the number of empirical studies conducted with teachers is limited. Furthermore, other accounts proposed by Allchin (2011), Irzik and Nola (2011), and Mathews (2014) have not yet provided empirical investigations of their framework in the area of teacher education. Additionally, RFN as a novel account of NOS has some empirical studies on its application in teacher education (Sarıbaş *et al.,* 2015; Kaya *et al.,* 2019; Kelly and Erduran, 2019; Cullinane *et al.,* 2022; Erduran *et al.,* 2020). However, all these studies involved pre-service teachers focusing on teaching all RFN or some of the RFN categories. Research conducted with in-service teachers is limited, and it does not include implementation (e.g., Demirel *et al.,* 2023; Beeghly *et al.,* 2024; Kurt and Kaya, 2024). Hence, the current study may contribute to the literature by providing empirical evidence on the implementation of RFN through a PD program for in-service teacher education.

It was found that studies conducted with teachers primarily focused on determining their NOS views or the changes in their perspectives about NOS (Tairab, 2001; Aslan, 2009; Doğan and Abd-El-Khalick, 2008; Kits, 2011). However, the current study also aimed to investigate how teachers translate their NOS learning into classroom practices. It was found

that even though teachers have some accurate beliefs about NOS, they cannot reflect these beliefs in their practices due to various reasons (Akerson and Abd-El-Khalick, 2003). In contrast, this study contributes to exploring teachers' experiences, how they translate their learning into practice, their strengths and weaknesses in classroom instruction, and the impact of collaborative work on teacher learning. Thus, this study also focused on the diverse professional knowledge bases of teachers.

This study also provides methodological contributions to science education by introducing an innovative professional development (PD) approach for teaching the RFN to in-service science teachers. Firstly, during the study, workshops were developed to teach RFN to in-service science teachers. Unlike prior RFN-based studies, which often focused on pre-service teachers (e.g., Kaya *et al.,* 2019; Cullinane and Erduran, 2022), this research designed and implemented workshops that uniquely integrated collaborative and reflective activities tailored to in-service teachers' practical needs. Distinct from traditional teacher education programs, which often adopt lecture-based or seminar-style formats with limited participant interaction (Borko, 2004), these workshops fostered a collaborative learning environment. Additionally, differing from conventional PD programs in Türkiye, these workshops allowed teachers to reflect on their experiences and develop materials through collaboration with their colleagues. By equipping teachers with tools to implement NOS in their classrooms, these workshops address the gap between theoretical NOS understanding and its practical application, a persistent challenge in science education (Lederman and Lederman, 2014). The resulting materials and workshop framework hold substantial potential for informing future in-service teacher education programs, enabling educators to teach NOS in a manner that is both accessible and impactful for students.

Another significant contribution of this study is the use of multiple case study designs. To examine each case in depth, it is suggested to utilize diverse data sources (Yin, 2003; Cresswell, 2018). In the current study, diverse data sources, including individual interviews, teacher journals, lesson plans, group discussions, and classroom observation protocols, were employed to determine the change in science teachers' perceptions of NOS, their transformation of NOS into their instructional practice, and the effect of the reflective/collaborative nature of the PD program on their learning and experiences. Thus,

studying multiple case designs provided benefits for understanding each case in depth through diverse data sources.

Teacher professional development in Türkiye has undergone a significant transformation in recent years, shifting from face-to-face to predominantly online formats, particularly following the COVID-19 pandemic. The Teacher Information Network (ÖBA), an asynchronous online platform managed by the Ministry of National Education (MEB, 2022), enables teachers to access training on diverse topics at their convenience, offering flexibility in both content and scheduling. While this digital shift aligns with global trends toward technology-enhanced PD (Dede, 2016), it has raised concerns about the depth and interactivity of such programs, which often prioritize accessibility over practical, classroom-focused outcomes (Borko, 2004). The current study contributes to this evolving landscape by proposing an innovative PD model that highlights the advantages of online learning while incorporating characteristics of effective teacher PD, such as collaboration, reflection, and practice-oriented activities (Darling-Hammond *et al.,* 2017). These insights have implications for the design of future PD programs, both in Türkiye and globally, demonstrating how digital platforms can support meaningful, impactful teacher learning when aligned with evidence-based PD frameworks (Desimone, 2009).

Overall, the current study may be unique for several reasons, such as conducting an empirical investigation based on a holistic framework of RFN with in-service science teachers, focusing on both teacher learning of NOS and enhancing their instructional strategies through classroom practices, developing workshops that integrate reflective and collaborative work among teachers, administering professional development via an online platform, and facilitating the construction of online learning communities. Furthermore, the current study aims to contribute to the literature on these unique characteristics.

1.2. Aims of the Study

The main purpose of this study is to investigate changes in science teachers' perceptions about the nature of science (NOS) based on the Reconceptualized Family Resemblance approach to Nature of Science (RFN) framework through the online reflective and collaborative professional development program. Moreover, it also aims to explore

science teachers' translation of NOS understandings into their instructional practices. Finally, the study examines science teachers' reflections on their experiences regarding collaborative work, learning, and teaching of NOS within the context of the professional development program. These aims are explored through the following research questions.

1.3. Research Questions

There are three primary research questions, along with several sub-research questions related to the data sources that will be utilized in the study. The research questions guiding the study are as follows:

- RQ1. How does participation in an online reflective and collaborative professional development (PD) program structured around the RFN framework shape science teachers' perceptions of the NOS?
    - RQ1.1. How does the online reflective and collaborative PD program, structured by the RFN framework, influence science teachers' visual representations of NOS?
    - RQ1.2. How does the RFN-based online reflective and collaborative PD program influence science teachers' perceptions of the NOS?

- RQ2. How do teachers translate their NOS understanding into instructional practices after participating in the RFN-based online reflective and collaborative PD program?
    - RQ2.1. How do science teachers integrate NOS-based activities into their lesson planning after participating in the RFN-based online reflective and collaborative PD program?
    - RQ2.2. How do science teachers integrate NOS-based activities into their classroom practices after completing the RFN-based online reflective and collaborative PD program?

- RQ3. How do science teachers reflect on their experiences with collaborative work, as well as learning and teaching of NOS within the context of the PD program structured by the RFN framework?

2. LITERATURE REVIEW

This section provides an overview of the literature related to the study. The following section covers, first, a review of “Nature of Science (NOS) in Science Education” with the subtitles “Reconceptualized Family Resemblance Approach (FRA) to NOS (RFN),” “Science Teachers’ Perceptions of Nature of Science,” and “Visualization of the Nature of Science.” Second, the title “Science Teachers’ Knowledge, Beliefs and Practices” is explored through the subtitles “Teacher Learning” and “Teaching Nature of Science.” Finally, Teachers’ Professional Development” is introduced with the subtitles “Online Professional Learning Communities,” “Reflective and Collaborative Teacher Professional Development Programs,” and “Teachers’ Professional Development in Türkiye.”

2.1. Nature of Science (NOS) in Science Education

The studies of several philosophers, including Conant (1961), Kimball (1968), Klopher (1969), Showalter (1974), and Rubba and Anderson (1978), formed the basis for discussions on teaching the Nature of Science (NOS) in science education. These philosophers focused on the characteristics of scientific knowledge and processes, emphasizing the importance of teaching NOS in science classes, which has significantly influenced the objectives of science courses (Erduran and Dagher, 2014).

Scientific educators have developed new narratives and models over time for teaching NOS in science classes. These viewpoints include "The Consensus View of NOS" by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002); "Whole Science" by Allchin (2011, 2013); "Features of Science (FOS)" by Matthews (2012); "Family Resemblance Approach (FRA)" by Irzik and Nola (2011, 2014); and finally, "Reconceptualized Family Resemblance Approach (FRA) to Nature of Science (NOS)” by Erduran and Dagher (2014), which was later renamed as “RFN” by Kaya and Erduran (2016) to distinguish it from previous versions of FRA accounts.

One of the most influential approaches in science education is the 'consensus view' of the nature of science, which prominent researchers (McComas, 1998; Lederman *et al.*,

2002; Abd-El-Khalick, 2012) have described through a set of statements that include seven key tenets. This approach has been regarded as an agreed-upon perspective for teaching NOS in science education for a long time because these tenets have the potential to summarize previous studies and are easy to teach in science lessons. Lederman and his colleagues outlined seven tenets for teaching NOS in K-12 schools: (1) the tentative nature of scientific knowledge, (2) observation, inference, and theoretical entities in science, (3) the theory-laden nature of scientific knowledge, (4) the creative and imaginative nature of scientific knowledge, (5) the social and cultural embeddedness of scientific knowledge, (6) scientific theories and laws, and (7) the myth of the scientific method (Lederman *et al.*, 2002, pp. 500–502). However, over the years, several new models and approaches have been developed (e.g., Allchin, 2011; Irzik and Nola, 2011; Matthews, 2012; Allchin, 2013; Erduran and Dagher, 2014; Irzik and Nola, 2014), which criticize various aspects of the Consensus View.

These tenets generally focus on the characteristics of scientific knowledge. From this perspective, some science educators have criticized this strategy. For example, Allchin (2011) criticized the Consensus View for presenting a limited perspective of science, placing more emphasis on scientific knowledge and inquiry than on other kinds of scientific investigation, lacking awareness of alternative scientific methodologies, and omitting classification, experimentation, and data collection. Furthermore, because the Consensus View does not emphasize the differences among various scientific disciplines, students may develop misconceptions about the nature of science (NOS), mistakenly believing that the nature, history, and methodology of science are uniform across all fields. The clarity of the tenets has also come under scrutiny. For instance, the third tenet claims that scientific knowledge is theoretically based and subjective, yet it does not clarify whether it is also objective. Matthews (2012) also examined the seven tenets regarding their function in science education. He argues that these tenets can serve as a checklist in the classroom to encourage students to contemplate NOS issues. However, the seven tenets may raise concerns related to demarcation and hinder a thorough exploration of the various dimensions of NOS. Additionally, Hodsan and Wong (2017) criticized the Consensus View in their research, asserting that it is oversimplified, includes confusing aspects, and fails to consider a diversity of scientific processes and other factors. Consequently, this leads to simplistic understandings of NOS among students and teachers, limiting the breadth of science curricula. As a result, alternative approaches to the Consensus View have emerged.

In relation to the reliability issue, Allchin (2011, 2017) incorporated parts of the Consensus View principles into several dimensions. He referred to this broadening as ‘Whole Science’ because it included both experimental and social components. In his proposal, he focused on the science curriculum and claimed that it lacks the inclusion of controversial issues. Conversely, a set of dimensions helps students understand how reliability affects the growth of knowledge and how science functions. There are three main dimensions: conceptual (e.g., alternative explanations, error and uncertainty, conceptual change), observational (e.g., accuracy, precision, role of systematic study, ethics), and sociocultural (e.g., collaboration and competition among scientists, role of gender, credibility, academic freedom, funding, peer review, norms) (Allchin, 2017). Additionally, according to Allchin (2017), Whole Science is more comprehensive and all-encompassing than the Consensus View in terms of its varied dimensions, and these aspects may aid students' decisions when they encounter complementary or opposing concepts. However, it is criticized the Whole Science perspective for misrepresenting the NOS idea, lacking support, and applying their paradigm in real-world settings, noting that decision-making does not simply consider NOS comprehension.

In contrast to the rigid and diverse vocabulary of “Nature of Science,” Matthews (2012) sought to replace it with "Features of Science" (FOS). One reason for this is to prevent the incorrect use of various dimensions. Accordingly, the NOS refers only to the epistemological and sociological components of science, whereas the FOS also takes into account political, educational, historical, commercial, and ethical issues. Additionally, Matthews (2012) asserted in his study that FOS strongly emphasizes an awareness of historical and philosophical consciousness. Furthermore, FOS addresses concerns related to feminism, constructivism, and realism that are not considered by other systems.

In educational settings, it has been argued that teachers need to have a deeper understanding of NOS, even though it is not mentioned in the definition of FOS. He advised that teachers discuss knowledge, hypotheses, evidence, observations, idealization, and other scientific concepts in their courses. Although Matthews offered compelling arguments for the expansion of scientific traits, Erduran and Dagher (2014) contended that he omitted a clear justification for his selection criteria. Thus, these ideas seem to be a collection of different concepts, some of which possess an epistemological perspective while others take

a philosophical or alternative viewpoint. Consequently, they proposed categorizing these concepts into a few groups to enhance their clarity (Erduran and Dagher, 2014).

Irzik and Nola (2011, 2014) introduced the "Family Resemblance Approach (FRA)" as an alternative to the Consensus View. Wittgenstein's "family resemblance" theory claimed that concepts cannot be defined solely by their necessary circumstances and essences. This theory demonstrates that there can be shared characteristics among all sciences, but these characteristics cannot be used to define science; instead, they illustrate features of science. Irzik and Nola (2011, 2014) adapted this idea into their NOS framework. They provided several examples, such as the term "game" and core characteristics of science across various disciplines, including "observation." Consequently, they divided science into two main categories: cognitive-epistemic aspects and social-institutional systems of research. Each category contains four subcategories, emphasizing issues of domain generality and specificity. Irzik and Nola (2011, 2014) made significant philosophical contributions to the theoretical growth of NOS in their works. They (2014) also highlighted that these categories are flexible and can expand by incorporating new ones.

Erduran and Dagher (2014) expanded the scope of each category, added more categories to the social-institutional aspects of science, and provided some educational applications of FRA in science lessons. Thus, they reconceptualized Irzik and Nola's (2011) FRA to NOS framework for teaching NOS in science education. Kaya and Erduran (2016) used the acronym "RFN" (Reconceptualized Family Resemblance Approach (FRA) to Nature of Science (NOS)) to distinguish it from Irzik and Nola's framework. The socio-institutional dimensions of NOS include three additional sub-categories added by Erduran and Dagher (2014): political power structures, financial systems, and social organizations and interactions. Finally, RFN addresses eleven meta-level sub-categories encompassing both cognitive-epistemic and social-institutional components of science in a logical, systematic, comprehensive, and pedagogical manner (Kaya *et al.*, 2019). Additionally, because RFN employs meta-level categories rather than declarative assertions, it can cover a wide array of concepts comprehensively and adjust concerns about domain generality and specificity for each sub-category across various disciplines. As a result, it may provide learners with a broad and systematic understanding of NOS (Kaya and Erduran, 2016). In the next section, RFN is presented along with all sub-categories.

To effectively teach NOS in science lessons, Erduran and Dagher (2014) designed Generative Images of Science (GIS), along with curriculum content, learning objectives, and outcomes for each sub-category of RFN. Additionally, RFN may provide guidance to science teachers on how to present pedagogical and instructional content about NOS. Teachers can introduce different categories into their classrooms. In their study, Erduran, Dagher, and McDonald (2019) also summarize and discuss the contributions made by various RFN studies in science education conducted with K–12 students, future science instructors, science textbooks, curriculum analysis, and more. The research showed that RFN can be seen as an effective strategy for addressing science in a collaborative, visual, and holistic way. Therefore, in the current study, RFN aimed to educate science teachers through a collaborative and reflective professional development program. The next section explains the RFN approach in more detail.

2.1.1. Reconceptualized Family Resemblance Approach to Nature of Science (RFN)

Erduran and Dagher (2014) created some Generative Images of Science (GIS) to illustrate the various RFN components. One of these that addresses every facet of RFN is the FRA Wheel (see Figure 2.1). It consists of three rings: the inner circle illustrates the cognitive-epistemic systems of RFN, while the middle and outer circles illuminate the social-institutional elements of FRN in a comprehensive manner. The cognitive-epistemic systems of RFN consist of the aims and values of science, scientific practices, methods and methodological rules of science, and scientific knowledge. The social-institutional elements of FRN include seven subcategories: professional activities, scientific ethos, social certification and dissemination, social organizations and interactions, political power structures, and financial systems. Each RFN category is summarized separately, detailing their content, the visuals (developed by Erduran and Dagher (2014) for teaching tools), and suggestions for how to teach them in science lessons.



Figure 2.1. FRA wheel: Science as a cognitive-epistemic and social-institutional system (Erduran and Dagher, 2014, p.28).

2.1.1.1. Aims and values. Erduran and Dagher (2014) developed a triangle (see Figure 2.2) that illustrates the epistemic, cognitive, and social dimensions of aims and values (AV). These dimensions include objectivity, novelty, accuracy, empirical adequacy, critical examination, addressing anomalies and counterinstances, and taking challenges seriously as epistemic-cognitive dimensions, as well as addressing human needs, decentralizing power, honesty, and equality of intellectual authority for social dimensions.

According to Erduran and Dagher (2014), aims and values serve interchangeable functions. They impact the selection of theories and methodologies, as well as the growth and development of knowledge. They employed a triangle model to conceptualize the functions of aims and values in science, with the range of values represented by one corner of the triangle, which complicates the distinction between them and establishes continuous boundaries.

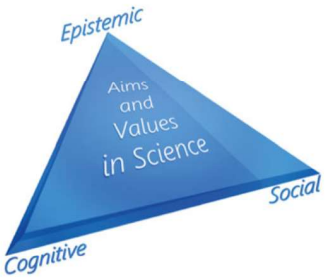


Figure 2.2. Aims and values in science (Erduran and Dagher, 2014, p.49).

In terms of educational applications of aims and values, it is argued that including aims and values in science classes teaches students how to conduct scientific inquiry and interpret scientific investigation from a broad viewpoint, as well as how to collect precise data and create more compelling explanations (Erduran and Dagher, 2014). They also provided a formative assessment rubric to demonstrate how to assess students' performance and attitudes toward specific values (Erduran and Dagher, 2014, p. 55).

2.1.1.2. Scientific practices. Erduran and Dagher (2014) argued that in school science, the products of science or the processes of science present problematic issues. While the former informs learners about scientific practices in a disconnected manner, the latter fails to address the role of various types of scientific practices in the development of scientific knowledge. They also discussed the distinctions between scientific practices and scientific processes in terms of terminology. Although these terms are sometimes used interchangeably in the literature, the former refers to the methodology of research, while the latter encompasses both epistemic and discursive activities, making it a more general term. Consequently, the phrase "scientific practices" was preferred by the authors (2014). Additionally, scientific practices possess explanatory and predictive power that influence the theory chosen.

Erduran and Dagher (2014) used examples from literature to illustrate three different types of scientific practices: observation, classification, and experimentation. Irzik and Nola (2011) reportedly divided the data into observational and experimental categories, suggesting that both can be viewed as observations. They propose that hierarchical classification may facilitate the production of scientific knowledge by listing the requirements for hierarchical classification from the study by Kwasnik (1999) and providing excellent examples to teach scientific practices in science lessons (elements in the periodic table, animal tissues). Additionally, experiments can establish theories, while theories can also be applied to the investigation of scientific procedures. This indicates that experiments can be conducted solely by following scientific procedures and do not necessarily need to be based on theories.

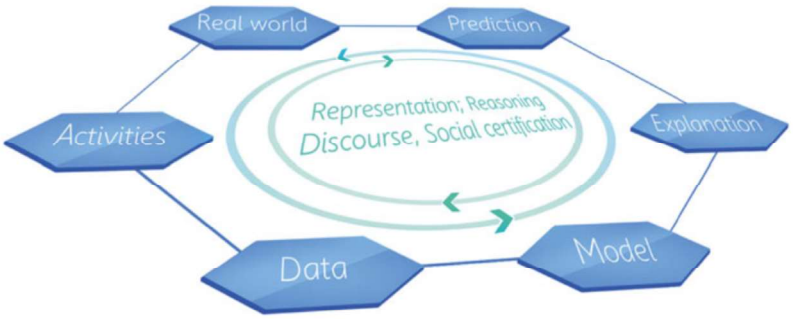


Figure 2.3. Benzene Ring Heuristic of scientific practices (Erduran and Dagher, 2014, p.82).

Finally, Erduran and Dagher (2014) developed "Benzene Ring Heuristics (BRH)" (see Figure 2.3). They used an analogy where carbon atoms represent scientific practices which are real world, prediction, explanation, model, data, and activities (classification, observation and experimentation), while the constantly flowing electrons symbolize the interconnectedness of these practices. Therefore, representation, reasoning, discourse, and social certification are positioned at the center of the model and function like electrons. The authors (2014) compared and contrasted their model with one adapted from NRC (2012) and found that, although both models share some practices, the BRH model is more dynamic, comprehensive, and memorable in illustrating the relationships between scientific practices and also serves as an effective pedagogical tool in science lessons.

2.1.1.3. Methods and methodological rules. According to Erduran and Dagher (2014), teaching the simplistic definition of scientific methods (M) in classroom science has led to students' misunderstandings about scientific methods. They suggested that scientific methods should encompass systematic information acquisition, the use of various data sources, and hypothesis testing regarding a research subject, rather than teaching step-by-step procedures as many textbooks address.

The diversity of scientific methods stems from the distinction between experimental and descriptive studies, and whether or not a hypothesis is being tested (Brandon, 1994). This means that measuring parameters may involve a lot of manipulation, but it doesn't always require testing a hypothesis. Brandon (1994) explains the relationship between experiments and observations using a simple two-by-two table known as Brandon's matrix

(see Table 2.1). Erduran and Daghers (2014) provided numerous examples of different scientific methods from the history of science. For instance, Darwin's observation in the Galápagos Islands, where he established a connection between the birds' beak structures and their feeding habits, illustrates a non-manipulative hypothesis testing method.

Table 2.1. Brandon's matrix showing the diversity of scientific methods (as cited in Erduran and Dagher, 2014 p.101).

	Manipulate	**Not- manipulate**
Test hypothesis	Manipulative hypothesis test	Non-manipulative hypothesis test
Measure parameter	Manipulative description or measure	Non-manipulative description or measure

Erduran and Dagher (2014) created a "gear" (see Figure 2.4) image to illustrate the interdependence and explanatory consilience of several M types. It was also suggested to use this image as a teaching tool in science lessons to help students understand the existence of various scientific procedures and how these methods influence the formation of different types of scientific knowledge.



Figure 2.4. The gears image shows how diverse M works synergistically (Erduran and Dagher, 2014, p.101).

Finally, Erduran and Dagher (2014) offered advice on how science textbooks and teachers might effectively teach M. For instance, teachers could foster a discussion-based environment and encourage students to develop their approach, build their hypothesis based on their research topic, and assess any potential methodological errors. Teachers should use

the Brandon matrix for different domains to show how various domains mainly employ the same or different methods. Additionally, science textbooks should encourage students to explore many types of scientific methodologies rather than presenting them as predetermined procedural processes.

2.1.1.4. Scientific knowledge. Erduran and Dagher (2014) categorized the different forms of scientific knowledge (SK) as theories, laws, and models (TLM). They provided a diagram (see Figure 2.5) that demonstrates how these forms of scientific knowledge work together and offers clear explanations for scientific occurrences. The TLM framework enables students to develop a coherent understanding of SK while considering its various forms and properties. Additionally, students can appreciate the value of scientific knowledge's explanatory power in problem-solving.

According to scientists' rankings, theories are categorized as central, frontier, or fringe. Central theories are those with the most investigations, coherent explanations, and therefore receive more support. Frontier theories are the most common, featuring unresolved elements. Finally, fringe hypotheses, founded on crank ideas, necessitate scientific investigation.

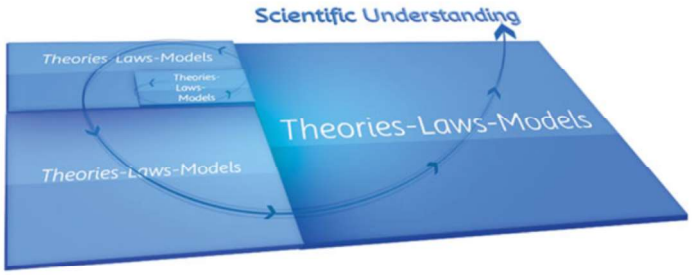


Figure 2.5. TLM, growth of SK and scientific understanding (Erduran and Dagher, 2014, p.115).

The TLM figure is a dynamic illustration demonstrating how various types of SK interact to produce scientific knowledge. There are two forms of knowledge growth. The first type is cumulative development of SK, which occurs when a new body of information is consistent with earlier ones and enhances its capacity for explanation. The second involves paradigm shifts, which happen when new SK does not align with the existing one and cannot

adequately explain the current scientific knowledge. Additionally, TLM features a domain-specificity characteristic. TLM emphasizes the importance of particular standards or criteria in knowledge growth. Consequently, its structure remains dynamic. The scientific community establishes these standards, and scientists assess new discoveries in relation to established knowledge.

2.1.1.1. Social-institutional aspects of science. Teaching the social-institutional aspects of science (SI) in science classes can foster students' comprehension of the scientific enterprise, the influences on science, and how these influences affect the development of scientific knowledge (Erduran and Dagher, 2014). This category is divided into seven sub-categories (see Figure 2.6) by adding three categories: financial systems, political power structures, and social organizations and interactions to Irzik and Nola's version of FRA. Each sub-category is described with examples as depicted by Erduran and Dagher (2014).

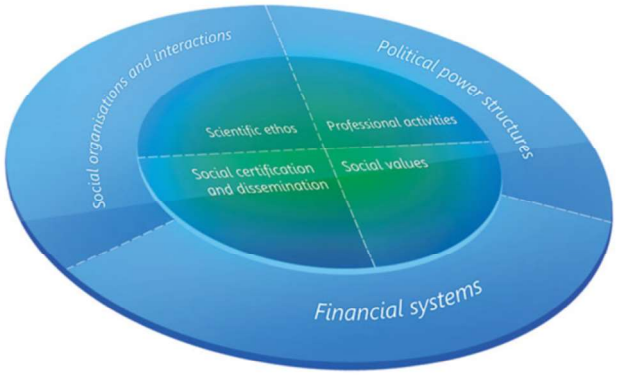


Figure 2.6. Science as a social-institutional system (Erduran and Dagher, 2014, p.143).

Professional activities encompass the skills necessary to conduct scientific research. Examples include attending conferences, presenting findings, publishing results, developing research proposals, seeking funding, and reviewing papers and grant applications (Irzik and Nola, 2014).

The *scientific ethos* refers to the behavior that scientists are expected to exhibit while conducting research. Students can learn how scientists value the trustworthiness of science by being educated about it in science classrooms. For example, this includes animal care, intellectual honesty, freedom, openness, and respect for research subjects and the environment.

The *social certification and dissemination* subcategory of SI focuses on how certain scientific communities validate scientific knowledge. Students may learn more about the various scientific communities and some issues related to competition in certification and dissemination of knowledge.

The *social values* category of SI encompasses broader moral concerns, including freedom and respect for the environment. Students who recognize these values can become more active citizens who support environmental causes, scientific research, and more.

The category of *political power structures* in SI examines the connections among scientists, their products, technologies, and between science and states. It has been found that throughout history, political or ideological issues such as colonization, capitalism, and religion have directly impacted science. Teaching these elements to students may help them avoid repeating past mistakes. Therefore, it is important for students to understand these relationships within the context of science.

The *social organizations and interactions* category of SI focuses on the institutions where scientists collaborate on various projects and hold professional and job statuses, among other things. Students who learn about this category may better understand how scientists work within social organizations and scientific institutions.

Finally, the *financial systems* aspect of the social-institutional dimensions of science focuses on budget issues in the development of scientific knowledge. Concerns about the commodification and commercialization of scientific information are also addressed. Therefore, it is important to teach students about the financial aspects of science.

Erduran and Dagher (2014) contrasted three different science education systems. They determined that all policies place insufficient emphasis on SI. Therefore, policies should be modified to holistically address SI concerns. Additionally, teachers may use various instructional techniques, including argumentation, case analysis, group discussions, etc., to enhance students' comprehension of social-institutional aspects of science.

There has also been an increasing number of research studies based on RFN in science education. The types of studies show diversity in educational interventions (K-12 students, pre-service science teachers, university students), informal science education, curriculum material analysis, experts' understanding of NOS, and students' and teachers' understanding of NOS (Cheung and Erduran, 2022).

In the context of educational intervention, RFN or certain categories of RFN were taught to diverse participant groups. For example, Akbayrak and Kaya (2020) focused on only the social-institutional categories of RFN for fifth-grade students in the Earth science unit. They used interviews and a Likert scale questionnaire, conducting descriptive and multivariate statistics, which led to increased student attention and motivation in learning the science topic. Moreover, Çilekrenkli and Kaya (2022) also studied fifth-grade students for a semester and covered all RFN categories. They employed various quantitative and qualitative data sources to determine the effects of intervention on students' development in NOS understanding. The results indicated that students in the experimental group performed significantly better than those in the control group in terms of total and category-based scores, except for the aims and values of science and scientific practices categories.

Petersen *et al.* (2020), in their study, aimed to introduce NOS elements to university students in the biology department through an exclusive-reflective approach that emphasizes socio-scientific issues. They utilized pre- and post-surveys and found that, compared to the pre-survey, the NOS knowledge of the 93 participants improved statistically significantly in 14 out of 24 items (58,3%) following the instructional unit. The pre-survey reveals a greater comprehension gap in the relationship between the environment, theory, and law, while the post-test results indicate considerable learning effects, particularly regarding subjective, social, and cultural influences on science.

There are also some studies on curriculum material analysis based on the RFN framework (e.g., Erduran and Dagher 2014b; Kaya and Erduran 2016; BouJaoude *et al.*, 2017; Yeh *et al.*, 2019; Cheung, 2020; Park *et al.*, 2020a, Park *et al.*, 2020b; Caramaschi *et al.*, 2022; Kurt and Kaya 2023; Okan and Kaya 2023). For instance, Kaya and Erduran (2016) examined how the RFN framework can assist in analyzing science curricula and identifying NOS-related gaps. By comparing two Turkish curricula to documents from the

USA and Ireland, they found that while the cognitive-epistemic aspects of science were acknowledged, the social-institutional dimensions were underrepresented. Notably, the Irish curriculum emphasized scientific ethos, while the Turkish one mentioned social organizations and interactions. Overall, they concluded that the categories of professional activities, financial systems, and political power structures within the RFN were only limitedly covered in all the documents.

Caramaschi *et al.* (2022) conducted an analysis of how the NOS was addressed in the Italian physics curriculum documents. They combined epistemic network analysis and FRA to examine the interconnections of FRA categories. The findings indicated that the curriculum documents have only minimally focused on the SI aspects of RFN.

Additionally, Kurt and Kaya (2023) examined how the NOS is represented in the Turkish science curriculum through the lens of the RFN framework. They performed a content analysis of the curriculum used in primary and middle schools. Their findings indicate a stronger emphasis on cognitive-epistemic aspects, with scientific practices being the most prominent category. In contrast, references to social-institutional elements, such as political power structures, were minimal.

Moreover, Kaya, Erduran, and Okan (2025) examined how NOS is addressed in the high school physics, chemistry, and biology curricula from Türkiye. The results reveal a strong emphasis on the cognitive-epistemic aspects of NOS, notable differences across the science subjects, and inconsistent progression of NOS themes across grade levels.

In another study, Okan and Kaya (2023) investigated the representation of the RFN categories in the 8th grade Turkish science textbook. The findings showed that SP, M, social certification and dissemination, professional activities, and scientific ethos appeared most frequently in the activity sections of the textbook. In contrast, AV, SK, social values, financial systems, and political power structures were most often found in the content sections, which indicates an inadequate representation of NOS.

The findings are similar to those of another study conducted by Xie, Wang, Li, and Bao (2025). The researchers examined how the NOS is portrayed across three consecutive

versions of China's physics curriculum standards over the past twenty years. The results of Epistemic Network Analysis indicated a persistent lack of emphasis on the SI, with specific omissions in categories such as professional activities, social organizations and interactions, and financial systems. Nonetheless, a gradual increase in references to social NOS categories suggests a growing recognition of this gap.

It can be said that RFN is a holistic, comprehensive approach, including meta-level categories. This approach was used in many studies for different purposes, such as determining perceptions of K-12 students, university students, and teachers, and analyzing curriculum and textbooks. In the current study, the theoretical framework is based on RFN. The following section summarizes the studies with pre- and in-service teachers based on the RFN approach.

2.1.2. Science Teachers' Perceptions and Understandings of the Nature of Science

Teaching and learning NOS has always been a fundamental necessity in science education (Lederman, 1992; Smith *et al.* 1997; Abd-El-Khalick *et al.*, 1998; McComas *et al.*, 1998). Major science education policy documents in the U.S.A. and national curriculum guidelines promote teaching NOS in K–12 education, as it is considered a critical component of scientific literacy (AAAS, 1993; NRC, 1996; NGSS Lead States, 2013; MEB, 2018). It has been asserted that enhancing science literacy skills largely depends on the emphasis placed on NOS in science lessons (Lokollo *et al.*, 2019). Furthermore, it has been claimed that teachers' scientific epistemological beliefs influence their teaching approaches, instructional strategies, and interpretations of knowledge and experiences (Deryakulu and Barge, 2003). Moreover, Roehrig and Luft (2006) emphasize the importance of teachers understanding NOS and teaching it effectively in science lessons for students to achieve scientific literacy. Additionally, Bartholomew (2004) claimed that there is a direct correlation between teachers' level of NOS knowledge and their ability to convey scientific knowledge to students. Thus, there is a significant amount of research conducted with teacher candidates and teachers to explore their perceptions of NOS.

Teacher education studies primarily focused on the Consensus View have been conducted with both pre- and in-service teachers. For instance, Brickhouse (1990) worked

with three experienced teachers and one inexperienced teacher to examine the teachers' views on NOS and their practices during science instruction. The research found that the alignment between the views and behaviors of experienced teachers was superior to that of inexperienced teachers.

To ascertain the opinions of pre-service science teachers and science teachers regarding the NOS and technology and their relationship with society, Rubba and Harkness (1993) continued to work with 26 pre-service science teachers and 19 science teachers. As a data-gathering technique, they developed and used the Science Technology Scale (STS). The research revealed that both pre-service teachers and in-service teachers had a sufficient understanding of the relationship between hypothesis, theory, and law, along with some misconceptions about the nature of science and its connection to technology and society.

Yakmacı (1998) examined the views of physics, chemistry, and biology teachers and teacher candidates regarding the NOS in his thesis study. The adapted version of the VOSTS-TR questionnaire developed by Akinhead *et al.* (1989) was used as a data collection tool. As a result of the research, most teachers hold a contemporary view on the tentative nature of scientific knowledge, but they maintain traditional views on the definition of science, the nature of observations, hypotheses, theories, characteristics of laws, features of the scientific method, the epistemological status of scientific knowledge, and the idea that science can be interpreted differently across various fields. Additionally, their views on the NOS varied according to gender, professional experience, and the field of science.

Lederman (1999) found that experienced teachers who possess a certain understanding of the NOS are inadequate in shaping their students' perception of science. By observing teachers in their classrooms and interviewing students, he discovered that while these teachers are aware of the changeability of scientific knowledge, creativity and imagination, observation, and the relationship between theory and law, they do not reflect these attributes in their classroom practices.

Another study conducted by Tairab (2001) aimed to investigate the views of pre-service science teachers and science teachers regarding science, technology, the characteristics of scientific knowledge and theories, the purpose of science and scientific

research, and the relationship between science and technology. He worked with 41 science teacher candidates and 54 science teachers. It was observed that the participants confuse the concepts of science and technology, hold utilitarian views that science operates for the benefit of humanity, possess adequate knowledge about the NOS, and have inadequate views regarding the nature of technology.

Akerson and Abd-El-Khalick (2003) observed a science teacher for one year to determine what specific supports were needed to enable the teacher to teach the concepts of NOS to her students. Observations and videotapes from the classroom, teacher NOS questionnaires and related interviews, teacher-researcher communications, and teacher and researcher logs were all used as data sources. It was found that although the teacher had the necessary understandings and intentions, they were not sufficient to translate into pedagogically appropriate instructional activities to make the targeted NOS components understandable to her pupils.

Kits (2011), in her doctoral dissertation, aimed to examine the possible relationship between worldview and conceptions of NOS for secondary science teachers who currently teach at a Christian school. The study involved eight secondary science teachers from a private Christian school. Participants' views on NOS were gathered through a Views of Nature of Science (VNOS) questionnaire and follow-up interviews. Participants' beliefs about nature, the natural world, and causality were obtained through a semi-structured interview and Test of Preferred Explanations (TOPE) questionnaire. The study found no predictable relationship between concepts of NOS and worldview ideas about nature and causality. Therefore, this study suggests that having a scientifically educated perspective on the world is not dependent on being "devoid" of religious ideas.

Moreover, Aslan (2009) examined science teachers' views on the NOS and how these views were reflected in the classroom environment in his doctoral study. To achieve this, the Views on the Nature of Science Questionnaire was administered to 74 science teachers working in various primary schools, and the classroom practices of 5 teachers were analyzed throughout a unit. Semi-structured interviews took place before and after the observations. As a result of the research, findings indicated that science teachers held naive, non-contemporary views about many aspects of the NOS.

Doğan and Abd-El-Khalick (2008) aimed to assess students' and science teachers' conceptions of NOS based on several variables, including gender, location, and the socioeconomic status of their city and region; disciplinary background; teaching experience; educational level; type of teacher training program; and students' socioeconomic status (SES) along with their parents' educational level. They gathered data from 2087 students and 378 teachers and used "Views on Science-Technology-Society" (VOSTS) items. They found that the majority of participants held naive opinions about most of the target NOS elements. Some of the target variables were correlated with teacher and student perceptions of certain NOS features.

Pelaez *et al.* (2025) aimed to explore the NOS views of preservice elementary teachers at a teacher education institution in the Philippines using a convergent mixed-methods approach. The study investigated the perspectives of 204 preservice elementary teachers on six NOS components: observation and inference, tentativeness, scientific theories and laws, socio-cultural influences, imagination and creativity, and scientific methods, employing a dual-response tool. Findings indicated that most preservice elementary teachers lacked well-developed views across these NOS dimensions.

There are also some studies based on the RFN framework, including educational interventions for pre-service science teachers. For instance, Sarıbaş and Ceyhan (2015) conducted an autoethnographic study on the scientific practice components of RFN by using the Benzene Ring Heuristic visual in science teacher education programs. They investigated pre-service science teachers' perceptions and representations of scientific practices. They used various data sources such as interviews, lesson plans, and audio recordings of lessons to determine the effect of the intervention. They found that pre-service science teachers' understanding of scientific practices improved, but they still maintained a naive understanding of domain specificity, ethics, and utility in science.

Moreover, Kaya *et al.* (2019) conducted an intervention aimed at developing pre-service science teachers' (PSTs) understanding of RFN over a 14-week period. They administered a 70-item questionnaire and individual interviews. The results from the quantitative analysis showed that the teacher education intervention resulted in a statistically significant overall improvement in PSTs' understanding of the NOS, particularly in the

categories of AV, M, SK, and SI of science. However, there was no notable change in their views on SP before and after the intervention. Based on the qualitative results, RFN enhances PSTs' understanding of NOS and how they teach NOS in their science lessons.

Furthermore, Erduran *et al.* (2020) aimed to determine the changes in pre-service science teachers' NOS perceptions through group discussions and FRA in two different national contexts: Türkiye and England. There were two groups in each context, and they participated in a structured set of group discussions separately. Finally, the groups in each context were contrasted with each other. Through group discussions, participants reflected their ideas on sticky notes. Then, a visual framework of NOS was presented to them, and they were expected to situate their ideas from the sticky notes within this image. It was found that although both groups of pre-service science teachers initially focused on the epistemic-cognitive aspects of science, they provided more nuanced examples regarding the social-institutional aspects of science after the introduction of the NOS visual.

Additionally, Cullinane and Erduran (2022) aimed to enhance pre-service teachers' understanding of NOS. They organized workshops based on the FRA approach and gathered data over a calendar year through interviews, lesson plans, and assessment tools. The findings indicate that while the two case studies in the research had similar involvement and attendance, their perceptions of what constituted NOS incorporation differed.

Takriti *et al.* (2023), in their studies, investigated how UAE pre-service science teachers view NOS through the RFN framework. The findings from the 70-item RFN questionnaire revealed that participants demonstrated a stronger awareness of the SI than of its cognitive-epistemic aspects. While some NOS components were well understood, the study also uncovered areas of confusion and misconceptions, such as misunderstandings about bias, gender, and politics in science, the notion of a single scientific method, and the differences between scientific laws and theories.

A multiple-case study was conducted by Beeghly, Gao, and Kruse (2024) to explore how three secondary pre-service science teachers' understanding of the NOS, their reasons for teaching NOS, and their instructional practices evolved after completing a NOS-focused course grounded in the RFN. Results indicated overall progress in the participants' NOS

views across all RFN dimensions. However, one participant still held misconceptions about scientific laws and theories. While two teachers developed complex, broader rationales for teaching NOS, the third remained focused primarily on emotional motivations. Despite gaining accurate NOS understanding and expressing sound rationales, only one preservice teacher effectively implemented explicit and reflective NOS instruction, centering on its socio-institutional aspects. The findings highlight the importance of extended exposure and practical experience in NOS for preservice teachers.

There are also studies focused on determining pre-service and in-service science teachers' perceptions of NOS without any educational intervention. For example, Kelly and Erduran (2019) investigated preservice science teachers' understanding of the epistemic, cognitive, and social aims and values of science through discussions on the introduction of 'nature of science' (NOS) in the new junior cycle science specification of Irish science education. They concluded that pre-service teachers demonstrated an understanding of some of the epistemic and cognitive aims and values of science, such as empirical adequacy and objectivity. Additionally, they were aware of some inquiry-based teaching strategies for teaching NOS. In the context of teachers' understanding of RFN, the studies are limited.

Also, Aksöz (2019), in her dissertation, aimed to determine the effects of various variables such as branches, teaching year, school type, and educational level on perceptions of aims and values and social-institutional aspects of science. She utilized an adapted version of the RFN questionnaire and interviews as data sources. The quantitative data analysis revealed that instructors' means differ significantly based on their branches, but not when considering their teaching experience, educational levels, and types of schools. The study of the qualitative data showed that teachers' perceptions of certain RFN categories are limited. It was also found that pre-service and in-service teacher education are valuable for teaching NOS in school science.

Moreover, Azninda and Sunarti (2021) aimed to explore teachers' perceptions of the NOS using the RFN framework. They employed a qualitative approach to examine teacher responses across RFN categories and utilized a 70-item RFN Questionnaire adapted from Kaya *et al.* (2019). A total of 15 science teachers and 10 non-science teachers (including social studies and language teachers) participated in both the questionnaire and interview

phases. Interviews revealed that non-science teachers had different perspectives on NOS compared to their science counterparts across various RFN categories. However, quantitative analysis using the Mann-Whitney test indicated no statistically significant difference in overall RFN Questionnaire scores between the two groups. The study concludes that differences in NOS views between science and non-science teachers may arise from the distinct educational experiences and training they have undergone.

Demirel, Sungur, and Çakıroğlu (2023) investigated science teachers' perceptions of the NOS and how they incorporate NOS into their teaching practices based on the RFN framework. They worked with 13 in-service science teachers in Türkiye through semi-structured interviews. It was found that teachers often used the terms SP and M interchangeably. Many participants provided in-depth insights into the SI, indicating an awareness of the social elements of NOS aligned with the RFN framework. Regarding the integration of NOS into classroom instruction, the findings showed that teachers who dedicated more time to NOS tended to value its inclusion in science education.

In another study, Kurt and Kaya (2024) conducted empirical research based on the RFN framework to investigate science teachers' perspectives on NOS, the integration of NOS into the science curriculum, and their approaches to teaching NOS. Data were collected through interviews and the RFN Questionnaire with ten science teachers. Findings indicated that while participants generally demonstrated a moderate to strong understanding of NOS, some held limited or naive conceptions. Teachers perceived the inclusion of NOS in the curriculum, particularly regarding its SI, as insufficient. Moreover, their descriptions of NOS instruction rarely addressed the SI components.

Another empirical study was conducted by Kaya and Erduran (2024) that aimed to explore how physics, chemistry, and biology teachers perceive the NOS based on the RFN framework, considering the various domains of science. They employed both quantitative and qualitative methods. The findings showed that factors such as gender, teaching experience, and education level do not significantly affect teachers' views on NOS. However, differences in subject area influence how teachers perceive certain NOS components, highlighting the complexity of how subject expertise shapes NOS understanding.

The NOS is a critical component of scientific literacy, emphasized in science education policy documents and curricula globally, as it enhances students' understanding of scientific knowledge and processes. Research highlights that teachers' NOS understanding and epistemological beliefs significantly influence their teaching practices. It can be said that numerous NOS-based studies have been conducted in teacher education, specifically focusing on pre-service teachers. Although there is a significant number of RFN-based studies in various contexts, teacher education-based studies typically aim to determine teachers' perceptions of NOS concerning different RFN categories, and research addressing in-service teacher education, including interventions, is quite limited. This study can significantly contribute to the field of science teacher education by emphasizing science teachers' collaborative and reflective learning of RFN through an online professional development program. The next section presents studies conducted on the visualization of NOS.

2.1.3. Visualization of the Nature of Science

The use of drawings serves as an effective tool for participants to express their feelings and thoughts creatively (Erduran and Kaya, 2018). Since visualization plays a significant role in how science is conducted, it is suggested that it should also have a major impact on how science is taught (Gilbert *et al.*, 2008). The ability to visualize concepts is essential to learning, particularly in the sciences, where students must learn to navigate between different forms of representation. Visualization is also considered one of the components of metacognition known as 'meta-strategic knowledge,' which enables one to understand the thinking behind the thinking (Zohar and Ben-David, 2008). Additionally, it can aid in understanding what and how science teachers comprehend NOS (Erduran and Kaya, 2018). Furthermore, Gilbert *et al.* (2008) suggested that visual representation can support the development and monitoring of understanding.

The studies on visualization have diverse focuses, including learning scientific concepts, self-perception, professional identity, ethical stances, visual data in science textbooks, and understanding the NOS (e.g., Eilam and Gilbert, 2014; Barak, 2017; Patrick, 2017; Winter and Astall, 2017; Erduran and Kaya, 2018). For example, Eilam and Gilbert (2014) examined the significance of visual tools in science instruction in their books. They

assessed how effectively instructors use various diagrams to clarify biology and chemistry concepts. They also explored ways to enhance the representational competence of science teachers and described the effects this has on their instruction. The results indicated that teachers faced challenges in creating visuals that exist in two ontological forms: internal and external images.

Another study conducted by Tippet (2016) aimed to examine the usage of representations in science lessons, whether ‘learning science from representations’ or ‘learning science with representations.’ A thematic analysis was conducted to examine 80 research studies published between 2000 and 2014. The results showed that both interpreting and creating representations can provide a better understanding of scientific concepts.

There are also some studies focused on students’ learning through interpreting or creating representations. For example, Glynn and Takahashi (1998) examined the role of an elaborate analogy in middle school students' learning of science. This analogy contains both graphic and text components and represents the function of cell parts. It was found that the analogy plays a mediating role between the students’ prior knowledge and the new knowledge in the text, making the target concept more understandable and memorable.

Treagust, Chittleborough, and Mamiala (2002) discussed the development and evaluation of a tool to assess secondary students' comprehension of scientific models in their study. They worked with 228 secondary science students and focused on five themes: ‘are scientific models as multiple representations’; ‘models as exact replicas’; ‘models as explanatory tools’; ‘how scientific models are used’; and ‘the changing nature of scientific models’. They concluded that students widely understand the importance of scientific models in learning science. Additionally, students’ interpretation of the term "scientific model" depends on their experiences and individual understandings. Thus, it was suggested that there is a need to emphasize the role and the aim of the concept of models in science.

Patrick (2017) used interviews and drawings to examine the pre-service teachers’ knowledge of internal anatomy. The findings underscore that participants may possess detailed anatomical knowledge through drawings, yet interviews reveal deeper insights into their understanding, particularly emphasizing social interactions as a source of information.

This approach enriches the analysis but could be more concise while aligning with existing literature on social constructivism and knowledge creation in education settings.

In another study, Barak (2017) aimed to investigate how science and engineering undergraduates incorporate information and communication technologies (ICT tools) into their learning. By utilizing Reflective Drawing Analysis, the researcher discovered that ICTs play a central role in contemporary academic life. It is suggested to use Reflective Drawing Analysis as a method for understanding students' learning and thinking in the 21st century. According to the researcher, this approach is proposed as a way to encourage reflective thinking not only about what they learn but also about how they engage in their learning process.

Drawings were also used in science education to determine the professional identity of pre-service teachers. For example, Winter and Astall (2017) examined how preservice science teachers represent their current and evolving beliefs about teaching and learning science through drawings in the science method course. They used The Draw a Scientist Teacher Test Checklist (DASTT-C), which combines both drawing and written narrative components. The findings indicated that the method course gradually shifted preservice teachers' beliefs from a teacher-centered model to a student-centered one. The use of drawings proved instrumental in revealing these evolving beliefs, as they provided a visual medium for expressing complex ideas that might remain hidden through other methods.

There hasn't been much overlap between the NOS and visualization literatures, despite extensive investigations in both fields. The intersection of these bodies of literature has been minimal. According to Duschl and Erduran (1996), visual representations of scientific concepts can provide teachers and students with epistemic insight into abstract ideas about science. Compared to other NOS approaches, Erduran and Dagher (2014) in their FRA approach inherently emphasize the use of visuals. They produced a set of visuals for each category of NOS by reviewing the literature and aimed to use these visuals as a teaching tool to facilitate understanding of NOS.

Erduran and Kaya (2018), in their study, incorporated visual tools into a science teacher education program and aimed to demonstrate how the visual tools of scientific

knowledge and practices related to the nature of science (NOS) might be integrated into science teacher preparation programs to enhance pre-service teachers' epistemic awareness. The qualitative study of verbal data and visual representations collected before and after the intervention indicates that pre-service teachers' perceptions of NOS have improved. They suggested that future teacher education research would benefit from visual representations to assist teachers in expressing and challenging the epistemic foundations of science.

In another study conducted by Barak, Yachin, and Erduran (2023), the aim was to examine pre-service teachers' understanding of NOS through their drawings and writings. The study found a notable increase in pre-service science teachers referring to RFN categories related to scientific practices, methods, as well as scientific knowledge and the professional activities of scientists. Additionally, the FRA-related activities contributed to a positive trajectory, facilitating a shift from a learner-centered approach toward a more epistemic, social, and institutional perspective. This transition enhanced their understanding of NOS from both a learner's and a scientist's viewpoint.

Finally, Cheung, Oancea, and Erduran (2024) aimed to investigate students' meaning making of NOS through the interaction of visual, verbal, and written modes during collaborative discussions. Student groups engaged in explicit and reflective multimodal representation tasks during NOS lessons. They employed a collective case study design and collaborated with teachers to develop NOS instruction, recording focal student groups in two Grade 7 classrooms in Hong Kong as they created multimodal representations of NOS. The researchers found that students' learning of NOS is inherently multimodal, with each mode offering distinct benefits. The findings from this study provide valuable guidance for science educators, suggesting ways to integrate both drawing and writing, as both play essential roles in helping students understand NOS.

As a result, visual representations, such as drawings, are powerful tools in science education, enabling students and teachers to express complex ideas, enhance metacognition, and deepen understanding of the NOS. Studies highlight that visualization aids in learning scientific concepts, developing representational competence, and fostering epistemic awareness, as seen in works by Eilam and Gilbert (2014), and Erduran and Kaya (2018). Research also indicates that drawings enhance NOS understanding when integrated into

teacher education, particularly through the Family Resemblance Approach (FRA) (Erduran and Dagher, 2014; Barak *et al.*, 2023). In the current study, visual representations are intended to be used as a data source to determine the changes in science teachers' perceptions about NOS through the collaborative and reflective professional development program on NOS. Through the PD program, it is also intended to benefit from the visual representations of diverse RFN categories developed by Erduran and Dagher (2014) to reinforce the efficacy of programs such as the FRA Wheel, Benzene Ring Heuristics, TLM Table, etc.

2.1.4. Operational Definition of NOS Perception

Perception of the Nature of Science (NOS) is defined as the degree to which a participant understands diverse cognitive-epistemic and social-institutional aspects of science, based on Erduran and Dagher's (2014) Reconceptualized Family Resemblance Approach to Nature of Science. These categories include aims and values, scientific practices, methods and methodological rules, scientific knowledge, professional activities, scientific ethos, social certification and dissemination, social organizations and interactions, political power structures, and financial systems. Teachers with an informed perception of NOS can comprehend science as a holistic system, identify its diverse aspects, provide examples for each category, and possess the knowledge and skills to teach these categories in science lessons. For example, a teacher connects the *aims and values*—accuracy, objectivity, consistency, scepticism, rationality, simplicity, empirical adequacy, prediction, testability, novelty, fruitfulness, commitment to logic, viability, and explanatory power—to *scientific practices* such as observation, classification, experimentation, data analysis, explanation, modelling, prediction, argumentation, and reasoning; to *methods and methodological rules*, including manipulative and non-manipulative methods, such as hypothesis testing or non-hypothesis testing; and to *scientific knowledge*, encompassing theories, laws, models, and their interconnections. For the social categories, *scientific ethos* involves awareness of norms like organized scepticism, universalism, communalism, disinterestedness, freedom and openness, intellectual honesty, respect for research subjects, and respect for the environment; *social values* include social utility, environmental respect, freedom, decentralized power, addressing human needs, and equality of intellectual authority; *professional activities* enable communication of research through conference attendance, presentations, writing manuscripts for peer-reviewed journals, reviewing papers,

developing grant proposals, and securing funding; *social certification and dissemination* involve presenting work at conferences and writing manuscripts for peer-reviewed journals, where scientists' work is reviewed and critically evaluated by peers; *political power structures* create a political environment that influences the direction and use of science; *financial systems* mediate the scientific enterprise through economic factors, as scientists require funding to conduct their work, with state and national governing bodies providing significant funding to universities and research centres; and *social organization and interactions* shape the nature of interactions among research team members working on different projects, governed by an organizational hierarchy (Erduran, *et al.*, 2019, p. 316). In the current study, teachers' perceptions are explored through visual representations and individual interviews conducted before and after the online collaborative and reflective professional development (PD) program. The aim is to identify changes in teachers' perceptions of the NOS, focusing on how they refer to NOS categories and how they mention related codes in their drawings and interview responses.

2.2. Science Teachers' Knowledge, Beliefs, and Practices

The study of science teachers' knowledge, beliefs, and practices is central to understanding effective science education. Shulman's seminal work (1986, 1987) introduced a framework that categorizes teacher knowledge into seven domains, with Pedagogical Content Knowledge (PCK) being particularly influential. PCK represents the integration of content knowledge (CK) and pedagogical knowledge (PK), enabling teachers to transform subject matter into forms that are accessible to students. According to Shulman, PCK includes knowledge of instructional strategies, representations (e.g., analogies, examples), and students' (mis)conceptions, making it distinct from general pedagogical knowledge or content expertise alone. For science teachers, PCK is critical because it bridges scientific concepts with pedagogy, addressing students' preconceptions and facilitating conceptual understanding.

Beyond PCK, Shulman's model includes content knowledge (deep understanding of the subject matter), general pedagogical knowledge (classroom management, teaching strategies), curriculum knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of educational purposes (Shulman, 1986,1987). These domains

collectively shape teachers' beliefs and practices. Beliefs, defined as teachers' personal convictions about teaching and learning, influence how knowledge is enacted in classrooms. For instance, a teacher's belief in inquiry-based learning may lead to practices that emphasize student-led investigations. Practices, in turn, reflect the application of knowledge and beliefs in classroom settings, such as lesson planning, assessment, and interaction with students.

Research conducted over the past two decades has explored science teachers' knowledge, beliefs, and practices, frequently utilizing Shulman's framework. A study by Hanuscin (2011) examined elementary teachers' PCK for teaching the NOS through a three-year professional development program. The findings revealed that teachers who enhanced their NOS understanding were able to translate it into classroom practices, such as implementing explicit-reflective instruction to address students' misconceptions about scientific processes. This study highlights the significance of sustained professional development in improving PCK.

Many studies have been conducted to identify the relationship between teachers' knowledge, beliefs, and teaching practices (Brickhouse, 1990; Lederman, 1999; Munby *et al.*, 2001). The research findings show that teachers acquire information and beliefs as they gain teaching experience, and that their knowledge and views may or may not directly impact how they teach (Brickhouse, 1990; Lederman, 1999). This indicates that there is no linear relationship between teachers' practices and their beliefs. Numerous factors may shape teachers' actions in their classrooms.

The study by Fischer, Borowski, and Tepner (2011) examined the relationship between content knowledge (CK), pedagogical knowledge (PK), and PCK among chemistry teachers. They found that teachers with strong CK were better equipped to develop PCK, but deficiencies in PK constrained their ability to effectively address students' learning difficulties. This underscores the interdependence of Shulman's knowledge domains.

A systematic review by van Driel *et al.* (2023) on science teachers' PCK emphasized its subject-specific nature, noting that PCK varies across disciplines (e.g., biology vs.

physics) because of differences in content and student misconceptions. The review also highlighted the importance of longitudinal studies to monitor PCK development over time.

Despite teachers believing in learner-centered education, some teachers' teaching strategies may be didactic (Lim and Chai, 2008). Teachers' ideas are shaped by a variety of internal and external circumstances, which also affect their behaviors (Buehl and Beck, 2014). Some of these elements include teachers' interests, disciplinary subculture, knowledge, skills, and abilities, teacher preparation programs, time and resources, curriculum and standards, teaching experience, school and classroom conditions, and educational policies, etc. (Wang *et al.*, 2020). In other words, teachers' actions and beliefs are situational, not context-free. Hence, it is critical to understand the context, what science teachers think, and how their thinking affects their actions.

The empirical studies examined the relationship between teachers' knowledge, beliefs, and practices. For example, Tillotson and Young (2013), in their project, generally aimed to evaluate how effective preservice programs are in supporting the overall development of science teachers. One of the goals was to identify the key factors that shape their teaching beliefs and behaviors after graduation. This project was a collaborative, multi-university research effort designed to address the need for concrete data on the effectiveness of science teacher education. They employed mixed methods, including diverse surveys and interviews such as Beliefs-Nature of Science Interview, Reformed Teaching Observational Protocol, Reflections on Preservice Program Experiences (RoPPE) Interview, etc. The results indicated that most teachers held instructive, teacher-centered beliefs, with fewer demonstrating transitional or reform-minded views. Over time, the general shift was toward more teacher-centered beliefs and practices. While many teachers used student-centered language like "guide" or "facilitator," their actual practices focused heavily on teacher control and delivering information. Differences across teacher preparation programs also influenced beliefs, with some programs producing more reform-minded educators than others.

In the study conducted by Saad and BouJaoude (2012), the aim was to explore the connections between teachers' attitudes toward science, their understanding and beliefs about inquiry-based learning, and their actual science teaching practices. They worked with

34 teachers and administered the Views of Science Inquiry questionnaire, which assessed how teachers perceive science and the scientific process, as well as the Attitudes and Beliefs about the Nature of and the Teaching of Science questionnaire, which measured their perspectives on the nature and instruction of science. Classroom observations were carried out to examine the teachers' actual instructional practices. The findings revealed that many teachers held limited understandings of the NOS and generally negative attitudes and beliefs about inquiry-based instruction. Furthermore, no consistent relationship was found between their knowledge and beliefs and their classroom practices.

Mansour (2013), in his study, investigated the relationship between science teachers' beliefs and practices. The researcher utilized a variety of data sources, including semi-structured interviews, observation notes, teachers' notes, and lesson plans. He identified three main patterns of beliefs and practices, which are traditional, mixed, and constructivist. The findings indicated that teachers with constructivist beliefs employ various teaching approaches to foster student engagement; however, these perspectives do not always manifest in a strictly constructivist manner. The study also found that the social context of the school significantly influences the application of constructivist perspectives.

In summary, science teachers' knowledge, beliefs, and practices are pivotal to effective science education, with Shulman's (1986, 1987) framework, particularly Pedagogical Content Knowledge (PCK), highlighting the integration of content and pedagogical knowledge to make science accessible to students. PCK, alongside other domains like content knowledge and curriculum knowledge, shapes teachers' beliefs and classroom practices, though the relationship is complex and not always linear, as shown in studies by Brickhouse (1990) and Lederman (1999). Factors such as teacher preparation, experience, and school context further influence beliefs and practices, with studies like Tillotson and Young (2013) and Saad and BouJaoude (2012) revealing that many teachers lean toward teacher-centered approaches despite reform-minded training, and inconsistencies often exist between beliefs and practices due to contextual and personal factors (Mansour, 2013). In the current study, teachers' knowledge, beliefs, and practices about NOS before and after the intervention are aimed to determine and develop through an online collaborative and reflective PD program. The next section presents key components in teacher learning and teaching the NOS.

2.2.1. Teacher Learning

Science teacher learning is crucial for enhancing teachers' knowledge, beliefs, and practices. This review examines science teacher learning through the lenses of social constructivist learning, identifying key components of effective teacher learning environments and analyzing empirical studies on teacher learning. Based on social constructivism (Vygotsky, 1978), professional learning theories (Darling-Hammond *et al.*, 2017), and sociocultural perspectives (Cochran-Smith and Fries, 2008), the review synthesizes recent studies to emphasize collaborative, reflective, and context-specific approaches. It also summarizes empirical research, including studies from Türkiye, to offer insights into designing impactful PD for science teachers.

Social learning theory posits that learning occurs through observation, interaction, and modeling within social contexts (Bandura, 1977). In education, this translates to teachers learning through peer collaboration, mentorship, and shared practices. Social constructivism, rooted in Vygotsky's (1978) work, emphasizes that knowledge is co-constructed through social interactions within a cultural and contextual framework. Vygotsky's concept of the Zone of Proximal Development (ZPD) suggests that teachers learn effectively when supported by more knowledgeable peers or facilitators, such as in professional learning communities or collaborative workshops (Vescio *et al.*, 2008). Social constructivist learning environments prioritize active participation, dialogue, and reflection, encouraging teachers to build on their prior knowledge and experiences (Baviskar *et al.*, 2009).

Effective teacher learning environments are characterized by several key elements that align with social constructivist principles, emphasizing active, social, and experiential learning (Baviskar *et al.*, 2009). Collaboration, as fostered through professional learning communities and collaborative PDs, enables teachers to co-develop lesson plans and reflect on practices, promoting shared knowledge construction (Vescio *et al.*, 2008; Sözbilir *et al.*, 2012). Reflective practices, such as journaling or peer discussions, help teachers critically analyze their teaching and adapt strategies to enhance classroom effectiveness (Le Cornu and Peters, 2009). Practice-oriented activities, including hands-on tasks like designing inquiry-based lessons, bridge theory and practice, making PD directly applicable to teaching contexts (Sözbilir *et al.*, 2012). Contextual relevance ensures that learning environments are

tailored to teachers' cultural and professional contexts, thereby increasing engagement and applicability (Desimone, 2009). Teachers prefer PD aligned with Türkiye's curriculum and addressing local challenges, such as resource constraints (Sözbilir *et al.*, 2012). Finally, sustained support through long-term, ongoing PD proves more effective than one-off workshops, allowing for iterative learning and implementation to foster continuous professional growth (Darling-Hammond *et al.*, 2017). In Türkiye, teacher PD has shifted to online platforms like ÖBA post-COVID-19, offering asynchronous training for flexibility (MEB, 2022). Thus, the characteristics of effective PD programs can be integrated into online platforms.

In their study, Goodwin and Darity (2024) aimed to explore the efficacy of virtual professional learning communities (PLCs) in supporting science teacher learning during the COVID-19 pandemic. They implemented a virtual PLC involving 50 secondary science teachers who collaborated to share and develop strategies for teaching ecosystems, focusing on enhancing their pedagogical content knowledge (PCK). The process included online discussions, strategy-sharing sessions, and reflective practices facilitated through digital platforms. The results demonstrated that the virtual PLCs significantly improved teachers' PCK, enabling them to design more effective, inquiry-based lessons. However, the study highlighted equity challenges, as technology access barriers in under-resourced schools limited participation, a concern relevant to Türkiye's ÖBA platform, which faces similar accessibility issues.

Sözbilir *et al.* (2012) aimed to examine the landscape of science education research in Türkiye through a content analysis of published studies, focusing on teacher professional development preferences. The researchers analyzed a range of articles to identify trends and priorities in Turkish science education. The process involved systematically reviewing studies to extract themes related to PD, teacher practices, and curriculum alignment. The results revealed that Turkish science teachers favor collaborative, practice-oriented PD programs that align with national standards, emphasizing hands-on activities and peer collaboration to enhance classroom practices.

This review emphasizes the significance of social learning and social constructivist approaches in science teacher education, highlighting collaboration, reflection, and practice-

oriented activities as essential components of effective professional development. Drawing from Vygotsky's (1978) social constructivism and Bandura's (1977) social learning theory, the PD program aims to foster teacher learning through peer collaboration, mentorship, and reflective practices within professional learning communities. The next section presents studies on teaching the NOS.

2.2.2. Teaching Nature of Science

The study conducted by McComas *et al.*, (1998) examines the impact of explicit instruction in the social studies of science, specifically in the areas of history, sociology, and philosophy, on changing teachers' views regarding the NOS. The study found that explicit instruction in the social studies of science successfully brought about changes in teachers' perspectives on the NOS. By engaging in specific instructional strategies that highlighted historical, sociological, and philosophical aspects of science, the teachers' views and understanding of the NOS were positively influenced. The results of the study suggest that incorporating explicit instruction in the social studies of science can effectively enhance teachers' knowledge and beliefs about the NOS.

Abd-El-Khalick (2013) introduced the distinction between "teaching with NOS" (structuring inquiry environments based on robust NOS understandings) and "teaching about NOS" (developing epistemological understandings of scientific knowledge generation). The study aimed to explore the dual goals of science education: fostering students' informed understandings of the NOS and engaging them in inquiry-based learning environments that resemble authentic scientific practice. The article proposes a model identifying three intersecting domains of teacher knowledge essential for effective NOS instruction: science content knowledge, inquiry-based pedagogical skills, and nuanced NOS understandings (general, content-specific, and historical). While these domains facilitate seamless NOS teaching, their implementation in practice relies on mediating factors such as curricular priorities and teacher beliefs. The article advocates for long-term, context-specific interventions to enhance teachers' NOS pedagogical content knowledge, highlighting its dual benefits for NOS instruction and inquiry-based learning.

Integrating the NOS into science education requires a specialized form of Pedagogical Content Knowledge (PCK), known as NOS PCK, which combines a deep understanding of NOS principles, strong science content knowledge, and pedagogical strategies to promote inquiry-based learning environments.

According to Wahbeh and Abd-El-Khalick (2014), NOS PCK includes heuristic NOS understandings, thorough content expertise, the ability to integrate NOS into science curricula, and the skills to design student-centered, inquiry-driven classrooms. This framework emphasizes that teachers must not only grasp NOS tenets but also connect these concepts to specific science topics, such as genetics or chemical reactions, to make them meaningful for students. Research consistently underscores the necessity of strong subject matter knowledge for effective NOS teaching (Schwartz and Lederman, 2001; Lederman *et al.*, 2013). For instance, a teacher with deep knowledge of biology can illustrate the tentative nature of science by discussing the evolving theories of evolution, thereby linking NOS to content.

Developing NOS PCK is particularly challenging, especially for pre-service teachers who often lack explicit training in blending NOS with content knowledge (Sorge *et al.*, 2019; Schiering *et al.*, 2023). Foundational PCK is typically cultivated during pre-service programs, but without targeted instruction, novice teachers struggle to effectively integrate NOS, often prioritizing content coverage over epistemological insights due to curricular pressures (Jain *et al.*, 2024). Empirical studies offer examples of successful interventions. For instance, Wahbeh's (2009) study, cited in Abd-El-Khalick (2013), engaged 19 veteran Palestinian teachers in a summer-long course that combined explicit-reflective NOS instruction, inquiry activities, and historical case studies. Teachers planned NOS-integrated units, and those with access to ongoing researcher support demonstrated greater success in classroom implementation, highlighting the value of sustained scaffolding. Similarly, Morrison *et al.* (2009) conducted PD with in-service teachers, utilizing explicit NOS instruction and metacognitive strategies, which resulted in improved NOS understandings and teaching practices. These studies indicate that developing NOS PCK requires long-term, context-specific support, including mentorship, collaborative planning, and opportunities for teachers to reflect on their practice. By embedding NOS within science content and fostering

inquiry-based environments, teachers can address both NOS and content goals synergistically.

In general, the studies emphasize the importance of specialized PCK for teaching the NOS, highlighting that explicit, context-specific professional development enhances teachers' knowledge, beliefs, and practices. McComas *et al.* (1998) demonstrated that explicit instruction in the social studies of science (history, sociology, philosophy) effectively shifts teachers' NOS perspectives. Abd-El-Khalick (2013) and Wahbeh and Abd-El-Khalick (2014) underscore that NOS PCK integrates deep NOS understanding, science content knowledge, and inquiry-based pedagogical skills to create student-centered, epistemologically informed classrooms. The developed PD program in this context incorporates tailored NOS PCK content, aiming to enhance teachers' knowledge, beliefs, and practices in integrating NOS with science content for effective, inquiry-driven instruction. The following section focuses on teachers' professional development.

2.3. Teachers' Professional Development

Defining teachers' professional development (PD) is challenging because it encompasses multiple dimensions and evolves throughout a teacher's professional journey. When existing research was examined, it was found that some definitions are based on traditional approaches, while others rely on new approaches (Sancar, *et al.*, 2021). According to traditional approaches, PD is typically characterized as procedures and activities designed to enhance instructors' professional knowledge, skills, and attitudes to promote student learning (Guskey, 2003). In contrast, new approaches emphasize improving teachers' learning and teaching skills in a collaborative, inquiry-based, and self-directed learning environment, considering their individual, social, and occupational dimensions (Sancar, *et al.*, 2021). Cochran-Smith and Lytle (1999), for instance, describe teacher PD programs as interactive and social learning grounded in discourse and community practice. They argue that teachers' involvement in formal or informal learning communities can effectively contribute to their development. Furthermore, Darling-Hammond and McLaughlin (1995) characterize PD as a process of personal and professional empowerment within one's area of expertise, where the teacher's professional identity is cultivated, and implicit knowledge

becomes explicit. In this study, a teacher PD program based on the new approaches is designed.

The characteristics of an effective PD program have also been discussed for a long time (Darling-Hammond and McLaughlin, 1995; Putnam and Borko, 1997; Wilson and Berne, 1999; Putnam and Borko, 2000; Hawley and Valli, 2000; Knapp, 2003; Desimone, 2011). For example, Desimone (2011) lists the features of an effective PD program as including content focus, active learning, coherence, duration, and collective participation. *Content focus* means that activities for professional development should concentrate on subject matter content and how students learn it. *Active learning* means that, instead of passively listening to lectures, teachers should have the chance to participate by giving and receiving feedback, reviewing student work, or giving presentations. *Coherence* means that any professional development in which teachers participate should align with previous professional development, their prior knowledge and views, as well as any state, district, and school reforms and policies. For *duration*, it was suggested that professional development activities should be spaced out throughout a semester, with 20 hours or more of contact time required. Finally, *collective participation* means that to create an interactive learning community, teams of teachers from the same grade, subject, or institution should engage in professional development activities.

Borko, Jacobs, and Koellner (2010) discussed contemporary approaches to teacher professional development in their study. They synthesize several reports (Darling-Hammond and McLaughlin 1995; Putnam and Borko 1997; Wilson and Berne 1999; Hawley and Valli 2000; Putnam and Borko 2000; Knapp 2003) from the literature and outline the characteristics of high-quality PD programs along with the process and structure of effective PD. The study found that the characteristics of effective professional development align with Desimone's (2011) research while also emphasizing other aspects and issues.

According to a synthesis of five studies, the content of the PD program should be situated in practice and address practical issues. The PD program should involve teachers in practical tasks related to teaching, assessment, observation, and reflection that illuminate how children learn and develop (Darling-Hammond and McLaughlin, 1995). This means that teachers' pedagogical content knowledge (PCK) (Knapp, 2003) should be strengthened

as content by focusing on teachers' own classroom practices. Additionally, the content of PD should focus on students' learning by connecting teachers' experiences (Putnam and Borko, 1997, 2000) with their students and emphasizing high standards for students.

The second issue was the process or structure of an effective PD program. According to the synthesis of the above reports, an effective PD program should be supported by models that include preferred instructional practices such as active learning, coaching, and collectively resolving practice-specific challenges (Darling-Hammond and McLaughlin, 1995; Knapp, 2003). Additionally, teachers should be treated in the same way that teacher educators expect teachers to treat students (Putnam and Borko, 1997, 2000). Furthermore, PD programs should promote active teacher learning. Darling-Hammond and McLaughlin (1995) suggested that a PD program should be grounded in inquiry and reflection. Teachers should identify what they need to learn and participate in creating the learning opportunities and procedures that will be applied (Hawley and Valli, 2000).

The other issue regarding the structure of PD programs is involvement in a professional learning community. All the reports indicate that PD programs should support collaborative learning environments for teachers. This means that PD is based on the collaborative work of teachers and focuses on communities of practice rather than concentrating on individual teachers (Darling-Hammond and McLaughlin, 1995). In other words, PD should provide opportunities for teachers to identify their needs while primarily emphasizing collaborative problem-solving (Hawley and Valli, 2000). Wilson and Berne (1999) focused differently on the benefits of creating learning communities that foster trust among members. Furthermore, teachers can redefine their teaching practices and enhance their interactions with one another through discourse.

Moreover, organizing professional development (PD) settings to align with goals and being school based is another characteristic of effective PD program structures. According to Hawley and Valli (2000), PD programs should be integrated into school-based operations. Finally, reports indicate that PD models and opportunities are sustainable and ongoing. This means that PD is continuous, providing support for further learning and follow-up. PD includes assistance from outside sources to introduce resources and fresh perspectives (Hawley and Valli, 2000).

Numerous studies present various professional development methods, including workshops, seminars, and conferences, alongside collaborative approaches like professional learning communities, teacher networks, and lesson study, as well as observational methods such as coaching, mentoring, and peer observation. These methods are often utilized in the practical application of teachers' professional development. This study focuses on collaborative PD programs designed to create an online learning community through collaborative activities. The next section presents research on the characteristics of online professional learning communities, reflective and collaborative teacher professional development programs, and teachers' professional development in Türkiye.

2.3.1. Online Professional Learning Communities

Professional development is a key source for enhancing teachers' instructional skills, developing new teaching techniques, and ultimately reflecting their growth in practice (Prenger *et al.*, 2017; González and Skultety, 2018). With the rapid advancement of information technology, the modes of teachers' professional development, learning content, learning resources, and environments are changing (MEB, 2022). According to Chen, et al., (2009) the format of PD for teachers has shifted from face-to-face interactions to blended or online modes. Additionally, teachers can access online learning activities at any time and from any location, thereby resolving the tension between their work and students' education.

When the effectiveness of teacher PD programs is considered, studies support that teachers should actively share knowledge and experiences with others, particularly in the form of groups or networks (Vescio, *et al.*, 2008; OECD, 2014; Vangrieken *et al.*, 2017). Such groups or networks provide a readily available supply of knowledge that is rooted in the day-to-day experiences of teachers and is best understood through critical reflection with others who share similar experiences (Vescio, *et al.*, 2008). These networks or groups are frequently referred to as "community" in the literature, reflecting a group of individuals who engage in a common enterprise aimed at fostering the collective construction of knowledge, understanding, and the discovery of new technologies relevant to their needs through social interactions (Vangrieken *et al.*, 2017). Being part of a community enables participants to be active in creating knowledge and meaning, engaging in collaborative activities, having

opportunities for reflection, and becoming experts in their learning process (Palloff and Pratt, 2007). One type of these communities is an online professional learning community.

The definition of online professional learning communities shows some differences in the literature. According to Hagel and Amstrong (1997), online professional learning communities refer to a setting where various types of information technology are used as a medium. On the other hand, Rheingold (1993) states that participants in online communities develop new types of "community" through a range of web-based communication channels (Liu, 2012). Compared to the first view, technology in the second view is merely a tool for creating communities; the members forge genuine bonds and shape the community's character. Liu (2012) signifies that technology in an online community simply serves as a tool for fostering a sense of community. As a result, technological support is crucial for encouraging online communication, but creating an online community should not be primarily focused on teaching people how to use technology. Moreover, Palloff and Pratt (2003) add two elements for creating an online learning community: collaborative learning and reflective practice.

There is a considerable number of research studies that support the importance of community in online courses and in online teaching in general (Shea *et al.*, 2005). According to Adams and Sperling (2003), creating an online learning community enables learners to transform teaching and learning in higher education. Additionally, an online learning community promotes collaboration and communication between teachers and experts (Rovai and Jordan, 2004; Macià and Garca, 2016). These and other research studies' findings have supported the hypothesis that building a strong learning community as the foundation for online learning is essential for an effective PD program.

Charalambos, Michalinos, and Chamberlain (2004) in their study listed the characteristics of successful online communities by synthesizing the studies of Levin *et al.* (1990), Palloff and Pratt (1999), Salmon (2000), and Harasim (2002) as follows: virtual professional learning communities unite individuals who, due to time or location constraints, collaborate online to achieve a shared objective. Tasks and subtasks are clearly defined, with participants fully aware of their roles and expectations. Members share a collective responsibility for the task and support one another, facilitated by accessible technology and

user-friendly communication tools. Effective leadership and skilled moderators guide activities, providing assistance and encouragement as needed. Interactions rely on open, constructive dialogue, with all members equally invested in the community's vision, goals, and outcomes. Mutual support exists among individuals and smaller subgroups, governed by clear participation rules and systems to monitor and address inappropriate behavior, ensuring a safe space for free expression. Activities are regularly assessed, with prompt feedback given. A level of structural interdependence promotes resource sharing and collaboration, while smaller peer groups within the community provide additional support and engagement.

Online PD enhances teachers' skills through flexible, accessible formats, shifting from in-person to online or blended models. Effective PD thrives in online professional learning communities, where teachers collaborate, share knowledge, and reflect on practices. These communities foster mutual support, clear roles, and open dialogue, using user-friendly technology to promote collective learning. In the current study, the effective online teacher professional learning community is aimed at being developed through the PD program to support teachers' professional growth.

2.3.2. Reflective and Collaborative Teacher Professional Development Programs

The roots of the concept of 'reflection' in the field of education are based on educational theorist John Dewey (1997) and philosopher Donald Schön (1983). According to Dewey, humans learn from their own experiences; thus, in a teaching context, reflection begins when teachers experience an event in their classroom, analyzing their experiences during or after the event. Schön (1983) developed Dewey's reflective thinking theory and distinguishes between reflection-in-action and reflection-on-action as the two main processes within reflection. Reflection-in-action means that teachers engage in reflection as they experience the event while teaching. On the other hand, reflection-on-action refers to teachers engaging in reflection after the event (Thumbi *et al.*, 2019). Another principle is the interaction among learners, which contributes to their meaning-making processes, including their social environment. In the current study, a reflective teaching approach will be adopted while developing the PD program for teachers.

Reflective teaching in nature involves meta-level self-awareness and affects teachers' development. It is evident that reflective journals, peer reviews, and feedback are commonly used methods for reflective teaching. In this learning process, teachers contemplate their teaching and cognition, critique themselves, and consider their future actions (Larrivee, 2000). Many educators have integrated reflective practices based on Dewey's philosophy in various ways into their teacher preparation programs, positioning them at the center of knowledge construction and skill development (Clarà *et al.*, 2017). According to Min, Akerson, and Aydeniz, (2020) reflection aids in developing critical thinking skills, forming practical theories and identities, and enhancing teachers' pedagogical content knowledge and teaching quality.

A study by Smith and Johnson (2018) examined the impact of a reflective collaborative approach on teacher professional development. The findings indicated that teachers who engaged in reflective collaboration experienced enhanced self-reflection, improved instructional practices, and increased student engagement. In another study conducted by Brown *et al.* (2019), teachers participated in a reflective collaborative group to explore and address challenges in their teaching practice. The results revealed that the collaborative approach fostered a supportive environment, promoted shared learning, and facilitated meaningful reflection, resulting in improved instructional strategies. Smithson and Clark (2020) conducted a qualitative study exploring the experiences of teachers involved in a reflective collaborative program. The findings highlighted the benefits of collaborative reflection, such as increased self-awareness, professional growth, and the development of a supportive professional community. In a longitudinal study by Martinez *et al.* (2017), teachers engaged in reflective collaborative practices over an extended period. The research demonstrated that sustained participation in collaborative reflection led to improved instructional decision-making, increased job satisfaction, and enhanced student outcomes.

The necessity of reflective and collaborative professional development programs in science teacher education is critical for enhancing teachers' pedagogical content knowledge (PCK), fostering constructivist learning environments, and strengthening their ability to teach the NOS. Reflective PD enables teachers to critically analyze their practices, which is particularly effective in addressing student misconceptions regarding the abstract concepts

of science. Collaborative PD, on the other hand, promotes peer sharing, the development of innovative teaching strategies, and a sense of collective responsibility through professional learning communities. Crotty (2024) found in a doctoral study that collaborative and reflective PD encouraged science teachers to adopt inquiry-based approaches and create student-centered environments, improving teaching practices and student outcomes through reflective dialogues and supportive professional conversations. Similarly, Çetin-Dindar (2022) demonstrated that collaborative, reflective environments in Türkiye enhanced science teachers' self-efficacy, highlighting the need for interactive PD to address limitations in platforms like ÖBA.

Recent studies emphasize that reflective and collaborative PD programs in science teacher education should be long-term, context-specific, and teacher-centered to maximize their impact. Vescio, Ross, and Adams (2008) underscored the effectiveness of professional learning communities in transforming science teaching by enabling teachers to reflect on student work, experiment with strategies, and incorporate peer feedback. McMinn, Aldridge, and Henderson (2021) found that reflective and collaborative learning environments boosted mathematics teachers' self-efficacy, a model that is adaptable to science education. In the Turkish context, Aydın *et al.* (2012) showed that reflective, collaborative PD supported pre-service chemistry teachers' PCK development, reinforcing constructivist approaches. These studies collectively highlight the indispensable role of reflective and collaborative PD in equipping science teachers with the pedagogical and epistemological tools needed to enhance student learning, urging platforms like ÖBA to incorporate more interactive and reflective components.

In summary, reflective teaching, rooted in Dewey's (1997) and Schön's (1983) theories, involves teachers analyzing classroom experiences either during or after events, fostering critical thinking and professional growth. Collaborative and reflective PD programs enhance science teachers' pedagogical content knowledge (PCK) and teaching practices by promoting peer sharing, inquiry-based strategies, and constructivist learning environments. In the current study, a reflective teaching approach is adopted while developing the PD program for teachers, focusing on customized content to enhance teachers' PCK for NOS, targeting improvements in their knowledge, beliefs, and practices.

2.3.3. Teachers' Professional Development in Türkiye

Teachers continue their vocation- and career-related training through in-service teacher training after beginning their careers. The term "in-service training" defines a set of tasks and demands typically placed on professional growth Akıllı, 2017). In Türkiye, the General Directorate of Teacher Training and Development is responsible for ensuring the cultivation and professional development of teachers. It prepares in-service training plans and programs for teachers (Kaya, 2020). In this regard, professional development societies, teacher-manager mobility programs, and school-based professional development have all been implemented in our nation to support teacher professional development.

According to Saiti and Saitis (2006), in-service training is the primary factor influencing teachers' professional development and is actively involved in enhancing their knowledge. Until 1993, all in-service training activities were conducted at the national level. To improve in-service training programs and the professional development of teachers, the Ministry decided to share its authority with universities and non-governmental organizations (Bayrakcı, 2009). After 2005, teachers' professional development increased as the Ministry prepared to implement a new curriculum. The Fatih Project, which began in 2010, was acknowledged to have a significant impact on topics related to in-service teacher education (Günel and Tanrverdi, 2014). To enhance in-service teacher education programs, the Ministry of National Education launched distance education programs in 2005. Finally, in 2021, the Teacher Information Network (Öğretmen Bilişim Ağı - ÖBA), developed to enhance teachers' professional development, employs these innovative strategies (MEB, 2022). The Ministry of National Education has prepared numerous professional development training sessions planned to be conducted as distance education in the 2022-2023 academic year.

ÖBA is a platform created to support the professional development of teachers and school administrators through distance education. It serves as a meeting point for professional growth and facilitates the sharing of best practices. On the ÖBA platform, central and local in-service training plans, in-service trainings organized both synchronously and asynchronously through distance education, a virtual library, professional development societies, teacher-administrator mobility programs, a school-based professional

development program, and the promotion of successful practices implemented by our teachers are offered to educators (MEB, 2022). ÖBA allows teachers to view the list of in-service activities they have applied for. Educators can choose the subject, type of training, duration, and the district where the training will take place. The content of the in-service teacher trainings primarily encompasses topics such as educational technology, teaching methods and approaches, special education, and personal development (Tunca *et al.*, 2015).

Additionally, TÜBİTAK, through its 4005 and 2237-A programs, provides substantial funding and training opportunities in innovative teaching practices and scientific project writing. The Teachers Academy Foundation (ÖRAV) offers both online and face-to-face training via its e-Campus platform, delivering content on differentiated instruction, play-based learning, and the use of artificial intelligence in education, reaching hundreds of thousands of teachers across the country (ÖRAV, 2024). EPDAD (Association for Evaluation and Accreditation of Teacher Education Programs) plays a vital role by accrediting faculties of education and organizing international congresses, such as the 7th ITEAC in 2024, to improve standards in teacher education (EPDAD, 2024). Additionally, the Erasmus+ Teacher Academies program, coordinated by the Turkish National Agency, supports teachers through long-term, cross-border professional development projects with European partners. Collectively, these programs contribute to elevating the quality of teaching in Turkey through modern, research-based, and collaborative training initiatives.

Bayar (2014) listed the components of effective professional development activities from the teachers' perspectives. Sixteen elementary school teachers were interviewed about their experiences. Additionally, a document analysis of result reports from Ministry of National Education trainings was conducted. It was found that any effective professional development activity should include a connection to current teacher needs, a match to current school needs, teacher involvement in the design and planning of PD activities, opportunities for active participation, long-term engagement, and high-quality instructors.

In conclusion, in Türkiye, in-service teacher training, managed by the General Directorate of Teacher Training and Development, supports professional growth through platforms like ÖBA, offering distance education, professional development societies, and school-based programs focused on educational technology and teaching methods. Effective

PD aligns with teachers' and schools' needs, involves active participation, collaboration, and reflection, teaching practices, and ensures long-term engagement. Given these characteristics, this study aims to develop an effective online teacher professional learning community through a PD program to address these needs and enhance teachers' skills and practices in teaching NOS based on the RFN framework.

3. METHODOLOGY

This section provides detailed information about the philosophical assumptions of the study, research design, the role of the researcher, participants, professional development program, data sources, data analysis procedures, threats to reliability, validity, and trustworthiness, limitations of the study, ethical considerations, as well as information regarding the implementation and findings of the pilot study.

3.1. Philosophical Assumptions

The philosophical assumption of this study is grounded in social constructivism. According to Vygotsky (1978), cognitive development initially occurs on a social level before it can happen within an individual. Additionally, Roth (2000) states that before information is internalized, its origins can be observed in how people interact with their surroundings and with one another. Therefore, within the social constructivist theory, context and culture play a crucial role in understanding how to construct knowledge based on this perspective. Consequently, an inductive approach to emergent ideas (through consensus) is derived from methods such as interviewing, observing, and analyzing texts methodologically (Cresswell, 2018).

There are also some assumptions of social constructivism. According to Kim (2001), ‘reality’ in social constructivism does not exist in advance; it is constructed through human interactions. ‘Knowledge’ is socially and culturally constructed when people interact with each other and with the environment in which they live. Jaworski (1994) used the terminology ‘taken-as-shared’ knowledge to represent this kind of social knowledge construction, which individuals seem to agree upon when certain conclusions are expressed in discourse. Finally, ‘learning’ emphasizes a social process affected by social activities such as interaction and collaboration.

The role of the instructor and the learning environment is shaped by these assumptions. According to Cobb and Bauersfeld (1995), instructors act as facilitators rather than teachers, helping learners develop their own understanding. They establish continuous

and interactive dialogues with learners to create effective learning environments. In this way, learners play an active role in their learning process. To create an effective constructivist learning environment, instructors should employ diverse teaching strategies and activities, such as allowing students the freedom to learn independently, incorporating question-and-answer sessions after each key topic, and assessing students both formally through testing and informally through dialogue or conversation (Kalina and Powell, 2009). Since communication is a significant medium for constructing knowledge in social constructivist theory, using various communicative methods can provide opportunities for learner interactions, such as role-play, concept mapping, drawing, and the use of artifacts (Amineh and Asl, 2015). In the current study, the learning environment is organized with consideration for the fundamentals of a social constructivist learning environment.

3.2. Research Design

This study is primarily based on qualitative research. When examining the common characteristics of qualitative research, they include “natural setting, researcher as the key instrument, multiple methods, complex reasoning through inductive and deductive logic, participants’ multiple perspectives and meanings, context-dependent, emergent design, reflexivity, and holistic account” (Cresswell, 2018). Thus, considering the elements listed by Cresswell (2018) in this study, the researcher gathers data by speaking with participants directly and observing them within their context instead of bringing them into a lab. The research collects multiple forms of data to examine documents, observe behavior, and interview participants, most of whom were adapted or developed considering the aim of the study. The researcher generates patterns, categories, and themes inductively and employs deductive reasoning when building themes based on the data. Through the study, the aim is to reflect participants’ meanings about the problem or issue, which represent multiple perspectives. The researcher clarifies her position in the study, explaining how she conveys her background and interprets the data. Finally, the researcher develops a complex picture by identifying multiple perspectives and the interactions.

This study employs a multiple case study methodology. A case study is defined as “an intensive study about a person, a group of people, or a unit, which is aimed at

generalizing over several units" (Gustafsson, 2017). Creswell (2018, p.300) also explained this method as,

> "Case study research is defined as a qualitative approach in which the investigator explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audio-visual material, and documents and reports), and reports a case description and case themes. The unit of analysis in the case study might be multiple cases (a multisite study) or a single case (a within-site study)."

There are different types of case studies based on the intent of the case analysis. A collective case study, or multiple case study, is one of them in which the researcher selects multiple case studies to illustrate the issue (Cresswell, 2018). This study is built on a multiple case study approach, where each case emphasizes a different set of research findings. The aim is to investigate how an online reflective and collaborative professional development program, structured by the RFN framework, affects science teachers' understanding of NOS and their perceptions, how science teachers transform their NOS understandings into their instructional practice, and finally, how they reflect on their experiences with collaborative work, as well as the learning and teaching of NOS, considering the professional development program structured by the RFN framework. Thus, the cases can be illustrated in Table 3.1.

Table 3.1. Three sub-cases for multiple case research design.

Sub-cases
Teachers' NOS understanding and perception
Teachers' transformation of NOS understandings into their instructional practice
Teachers' reflection on collaborative nature of PD program

3.3. Role of the Researcher

The author, as a researcher and instructor of the PD program, has diverse roles and responsibilities in different phases of the study. The researcher strives to fulfill the requirements of conducting a qualitative study. She employs rigorous data collection procedures by gathering and utilizing various data sources (Creswell, 2018). Thus, the researcher provides a detailed method by validating the accuracy of procedures such as triangulation of data sources or using peer review and presenting a thick description of codes

or themes. The researcher also pays attention to ethical issues. She obtains permission from institutional review committees before conducting the study and also secures consent from participants.

As an instructor, the researcher plays a facilitator role in the PD program. She presents the framework and allows teachers to explore related materials through collaborative group activities. In this process, the instructor employs diverse instructional techniques and uses online collaborative learning tools to enable learners to become active in their knowledge construction. The instructor encourages participants to work as a group, discuss the directed questions, and develop their lesson plans. Additionally, the instructor provides timely feedback to the teachers and encourages them to give each other feedback.

3.4. Participants

Researcher. The researcher is a science teacher in a public school with nine years of teaching experience. She is interested in teaching NOS in science lessons and teacher education. She has taught RFN in school science and has experience in pre-service and in-service science teacher education by working on three different projects as a researcher. Through these projects, she has gained experience in gathering diverse data sources, analyzing them, and contributing publications based on her findings. Additionally, she has conducted workshops for pre-service and in-service teachers at various universities. Thus, she is familiar with the study's framework and has previously studied with pre-service and in-service teachers, benefiting from these experiences while organizing and analyzing multiple data sources.

Science Teachers. Six science teachers working in Istanbul, Türkiye participated in this study. Convenience sampling was employed to reach more teachers. This approach is often used in qualitative research when the goal is to obtain participants who are readily available and willing to take part in the study. According to Creswell (2012), convenience sampling enables researchers to "select individuals who are easiest to access and willing to participate," which is particularly useful in educational research where time and access to participants can be limited. To reach the participants, the researcher contacted her instructors' graduate students through university professors, her colleagues who work in the

same and different schools, and social media (LinkedIn, Facebook, Telegram). At the beginning of the study, eight science teachers were willing to participate. One of them withdrew due to health issues before the pre-data collection process, and another opted out after the first workshop due to workload. Table 2 provides general information about participants' nicknames, education levels, years of service, and school types.

Table 3.2. General information about the participants of the main study.

Case ID	Participants' Nick Names	Education Level	Serving Year	School Type	Pre-NOS Learning Experiences
1	Aylin	MA student	4 years	Private	Taken NOS course at the university
2	Beren	MA student	4 years	Public	Taken NOS course at the university
3	Deniz	BA degree	6 years	Public	Taken NOS course at the university
4	Leyla	MA student	1 year	Public	Familiar to RFN
5	Melisa	MA student	9 years	Public	Familiar to RFN
6	Zeynep	MA student	4 years	Private	Taken NOS course at the university

In case study research, providing a detailed description of participants is essential for ensuring the credibility and contextual understanding of the study. This information allows readers to interpret the findings in light of the participants' backgrounds, experiences, and roles within the studied context. According to Merriam and Tisdell (2016), "rich, thick description" of participants enables readers to determine the extent to which the findings are transferable to other settings. Without such detail, interpreting the data may lack depth, and the study may fail to convey the complexity of real-life situations that qualitative research seeks to explore. Additionally, clearly defining who the participants are contributes to the transparency and trustworthiness of the research process (Yin, 2018).

In accordance with the importance of providing a rich and contextual understanding of participants in case study research, teachers were asked questions in their pre-interview protocols (see Appendix B) regarding their demographic details, including their schools, teaching approaches and practices, lesson planning and activities, professional development opportunities, learning styles, and prior knowledge of NOS. Based on this information, each case is described in the following section to offer a comprehensive context for interpreting the findings.

Case 1: Aylin. Aylin graduated from the Science Education Department at a public university in 2019 and had 3.5 years of teaching experience when she began the professional development program. She was employed as a full-time science teacher at a private school. Aylin was pursuing a master's degree in Science Education, although she had paused her thesis due to a disconnect with her interests.

Aylin's school provides excellent physical resources, including a comprehensive science laboratory. She effectively uses a smartboard in her lessons and prefers private books and materials over those supplied by the Ministry of Education. She incorporates real-life materials into her classroom activities and is pleased with the school's facilities.

She described her teaching approach as primarily constructivist learning. She begins her lessons by engaging students in a question-and-answer session, often using real-life examples, especially for 6th and 7th graders. She encourages students to share their knowledge and guides them in connecting their ideas to the lesson. Although she sometimes starts with direct instruction, she transitions to practical applications as foundational knowledge is established. She assesses students through both verbal responses and problem-solving tasks that reflect real-life challenges. After quizzes, she conducts review sessions to address any gaps in understanding.

According to her pre-interview, she often utilizes her previous lesson plans and activities from university, adapting them for her students while preparing her lesson plans. She designs her lesson plans weekly, typically on Sundays, for the upcoming week. Although she plans lessons, she remains flexible, adjusting based on student feedback. She focuses on using materials that students can either find at home or create themselves, avoiding pre-packaged kits unless necessary. She requests material suggestions from students a week in advance to plan accordingly. The lesson structure centers around project work, where students connect what they've learned to the products they create. She encourages self-reflection and self-assessment, asking students to evaluate their work before moving on to quizzes that include multiple-choice and open-ended questions based on their projects. Her activities are product-based, with students creating tangible items from the lessons. She employs methods like "Six Thinking Hats" and "Shoes on the Other Foot" for

socio-scientific topics, promoting different perspectives. Through project-based and socio-scientific activities, she fosters both creative thinking and practical application.

Aylin believes visual design-based PD programs are the most beneficial. She is studying visual communication design, which has enabled her to create more effective lesson materials while participating in this PD program. She prioritizes using software related to visual design for her professional growth instead of verbal or other non-visual methods. Aylin found collaborative development challenging because her teaching style differed from the traditional approaches she had previously employed. She acknowledged the importance of collaborative environments but struggled to find one, as teachers often feel too exhausted to engage effectively. Nonetheless, she discovered her school colleagues to be very supportive, as they are more experienced and open to her ideas. Regarding the PD program, she hoped to learn more about the NOS and improve her ability to engage students in discussions with opposing views on these issues. Her main concern was balancing her busy schedule with her commitment to the development program. Although she was involved in multiple areas of study and work, she was eager to invest the necessary time and effort.

Aylin stated that she learns best through observation and hands-on experiences in her pre-interview. Visual elements play a crucial role in her learning process, and she often incorporates visual communication and design into her teaching materials.

Aylin recalled studying the NOS in university, but several years had passed, so her memory of the details was somewhat vague. She remembers key concepts such as the notion that there are no absolute truths in science and that all knowledge is subject to scrutiny. She recalls from her university course that scientific knowledge evolves, meaning that something once considered true might later be disproven. She also remembered participating in a class activity where they debated the pros and cons of nuclear power, working in groups to argue either for or against the topic based on a balanced article. This experience left a strong impression on her, especially the confusion and chaos it created, as neither side could definitively prove their point. Another memorable activity involved cutting shapes from paper and trying to rearrange them to form a rectangle, which was later linked to scientific knowledge. Based on her pre-interview responses, Teacher Aylin’s undergraduate NOS

course reflects the Consensus View, incorporates some connections to socio-scientific issues, and includes limited teaching practices.

While she believes that NOS should be taught in science classes, she feels it is not adequately addressed in the current curriculum during her pre-interview. She argued that students often view scientific information as either completely correct or incorrect, without understanding that knowledge can evolve. She advocated for including NOS in the curriculum as a learning objective, as this would help students better understand the nature of scientific inquiry and become more open to questioning and critically analyzing information.

Case 2: Beren. Beren graduated from a public university with a degree in Science Education in 2021. She worked at a private institution for six months before moving to a public school after passing the KPSS exam. She has been teaching for four years and was employed at a socioeconomically disadvantaged school in İstanbul at the start of the PD program. Additionally, she was in the first year of her master's program in Science Education.

Beren described her school as having limited academic resources and facing infrastructure challenges. Internet access is unreliable, and the newly established laboratory lacks essential equipment, often functioning as a storage area and changing room for physical education classes. Academic performance among students is generally low, with only a small percentage showing potential for higher achievement. There is also a significant number of students with reading difficulties, diverse backgrounds, or special education needs. Despite these challenges, Beren appreciates the supportive atmosphere created by the school principal and her colleagues.

Beren prepares lessons with visually engaging presentations supplemented by videos from platforms like TikTok and YouTube to capture her students' interest. Her lessons often include interactive question-and-answer sessions, and she incorporates creative activities such as poetry and story writing at the end of units. However, large class sizes and limited resources hinder her ability to conduct hands-on experiments. Instead, she leverages digital activities and group competitions to engage her students.

Beren primarily relies on Ministry of Education textbooks, supplemented with additional teaching materials from publishers. Her lessons consist of two periods of content delivery, followed by two periods of reinforcement through digital activities or group competitions. Although she acknowledges the importance of experiments and modeling, logistical challenges and large class sizes have limited her ability to incorporate these methods effectively.

Beren prefers interactive, workshop-style professional development activities over passive lectures or videos. She values training that enhances awareness of inclusive teaching strategies and innovative approaches such as gamification and flipped classrooms. Furthermore, she actively collaborates with her colleagues by sharing teaching strategies, resources, and materials. Beren stated that she expects the PD program to provide innovative strategies to make her lessons more activity based. Additionally, she looks forward to networking with other teachers and learning from their practices. Her primary concerns were balancing her participation with personal commitments and effectively implementing new methods in her classroom.

According to Beren, she learns best through active notetaking and self-reflection. She finds visual aids and presentations with minimal text particularly helpful. She emphasizes the importance of summarizing and revisiting key points to enhance retention. Beren identifies herself as an active learner who retains information best through notetaking and review. When someone explains a topic, she focuses on noting key concepts and keywords highlighted by the speaker. Visual presentations that balance concise information with engaging visuals are her favorites, while text-heavy presentations tend to lose her attention. She enjoys interactive resources, such as those found on EBA (Education Informatics Network), where users can engage with content through quizzes and activities, making the learning process more dynamic and less monotonous.

She encountered the concept of NOS in her undergraduate studies but found the instruction lacking depth. Later, she revisited NOS concepts while preparing for the KPSS exam, where she learned about paradigm shifts and the evolution of scientific knowledge. She recognizes that students often perceive scientific knowledge as static and always present. For example, her students are surprised to learn about historical discoveries and the

processes behind concepts they take for granted. Beren believes that NOS should be integral to science education, helping students understand how knowledge is discovered, validated, and evolves. She thinks current curricula emphasize NOS in specific units with historical content, such as atomic models or the periodic table, during her pre-interview. However, she advocates for integrating NOS into all topics, including practical areas like electricity, to provide a broader understanding of scientific processes.

Case 3: Deniz. Deniz graduated from the Science Education department at a public university in 2015. After encountering challenges during the KPSS process, she shifted to the private sector, working in tutoring centers for 6 to 7 years. During the pandemic, she seized the opportunity to focus on her career and was fortunate enough to secure a teaching position. At the beginning of the PD program, she was in her second year of teaching at a religious public school in an underdeveloped region of Istanbul.

Deniz described her school as having low academic performance and a low socioeconomic status. Many students lack clear career goals, with some aspiring to work in the textile industry after graduation. The school has a significant number of Syrian students, some of whom struggle with Turkish and even resist learning the language. The teacher describes challenges in managing the classroom, especially with boys, who tend to be more difficult to discipline and engage. Despite these challenges, the teacher utilizes resources like EBA and private sources to enhance learning. The teacher also aimed to develop skills in cooperative learning through practical experience in the PD program. Additionally, the teacher participated in a TÜBİTAK project and hoped to further her knowledge through workshops.

Regarding her teaching style, the teacher begins lessons by asking students engaging questions. Visual resources like EBA videos help solidify concepts, followed by textbook explanations. The teacher frequently reviews the material through questioning to reinforce learning and keeps students alert by occasionally threatening oral quizzes. According to Deniz, her teaching approach is student-centered, starting with engaging questions to spark curiosity. She emphasizes making concepts tangible and utilizes real-life examples to connect the topic to students' experiences.

Deniz does not create formal lesson plans; instead, she prefers to plan lessons mentally, deciding in advance which activities to undertake and how to approach each topic. She considers the student profile and adjusts her methods accordingly. Her plans include using the textbook, taking notes, and engaging students in question-and-answer sessions. When conducting experiments, she emphasizes student participation; however, due to practical constraints, the teacher often performs the experiment while the students observe. Before starting an experiment, she introduces the materials and asks the students for their predictions. Afterward, she discusses the results and checks whether the intended learning outcomes were met. She revisits these experiments in later lessons to reinforce the learning.

Deniz believes that professional development (PD) programs for teachers should prioritize practical and personalized learning. She also emphasizes the importance of knowing how to stand and communicate effectively while teaching, suggesting that teachers be observed and receive feedback to aid their improvement. Additionally, she advocates for training on how to engage with various student groups, especially those in middle school, as communication with them can be challenging. Regarding collaboration, Deniz values teamwork and believes that working together with colleagues can foster creative ideas. She feels that while teachers sometimes collaborate in specific situations, such as preparing for common exams, there is overall insufficient ongoing collaborative effort. She recognizes the potential for increased collaboration to enhance teaching methods and strengthen the teaching community. Deniz had expectations for the PD program. She hoped to improve her lesson plan writing and wanted to assess the effectiveness of these plans once implemented in the classroom. She was also eager to refine her teaching methods to make science more engaging for students. However, she was concerned about possible challenges in collaborating with a colleague she might not agree with and worried about managing disruptive students within the confines of fixed lesson time before implementation.

Deniz reflects on her learning style, emphasizing that she learns best through visual and hands-on methods. She possesses a strong visual memory and can easily recall images from notes or textbooks after just a few repetitions. Unlike verbal learners, Deniz does not rely on memorization or rote learning; instead, she prefers to grasp the reasons behind concepts. She learns effectively by engaging in hands-on activities, experiencing, and

repeating. She also acknowledges that she sometimes has difficulty focusing, but she can remember well when her attention is fully on the subject.

Deniz believes her understanding of the NOS is somewhat limited. She recalls learning about it in university. Although she does not have extensive knowledge of NOS, she recognizes its importance in teaching students how science works. She discusses how science builds on prior knowledge, with discoveries often emerging from accumulated information and ongoing inquiry. Regarding the teaching of NOS in science classes, Deniz agrees that it is crucial for students to grasp this concept, as they frequently question the relevance of what they are learning. She believes that teaching NOS helps students understand that scientific knowledge evolves through a series of discoveries, and that nothing in science is fixed or certain. She also notes that curriculum topics, such as biotechnology, relate closely to NOS. Specifically, she mentions how understanding the relationship between biology and technology in the production of insulin exemplifies the application of scientific principles. Overall, Deniz considers the teaching of NOS essential for helping students comprehend the dynamic nature of science.

Case 4: Leyla. Leyla earned her undergraduate degree in a Science Education program at a public university and then pursued a master's degree while starting her teaching career. She was in her third year of the master's program in Science and Mathematics Education after completing her first year of teaching at the beginning of the PD program.

Leyla works at a public school that serves a large number of students, many of whom are foreign nationals or refugees. The school is situated in a socioeconomically disadvantaged area. She makes use of resources provided by the Ministry of Education, including textbooks and online materials like videos. In addition, she supplements these with extra resources that she finds helpful, such as activities and simulations that she searches for online, often in English. Although the materials are in English, she explains them to her students in Turkish, ensuring they understand the concepts despite the language barrier. She describes her students as coming from low socioeconomic backgrounds, many of whom have parents with low education levels. A significant number of students struggle with literacy. The school environment does not effectively support her personal goals. She feels there are not many young, enthusiastic teachers who share her interests or drive. Consequently, some

teachers do not contribute to the workload, leaving only a few to bear much of the responsibility.

Leyla is deeply committed to professional development, participating in training sessions on topics such as sustainability, climate change, and STEM. She stays informed by following international experts and exploring their activities online, and she has also taken additional courses on climate change as part of her master's program.

In her pre-interview, she articulated her teaching style, which encourages students to consider how scientific principles, such as cause and effect, relate to their everyday experiences and challenges them to critically assess the validity of scientific facts and theories. Throughout her lessons, she integrates critical thinking, emphasizing the interconnections among various pieces of knowledge. Leyla primarily employs the 5E model in her teaching. She reinforces learning through visuals and models, fostering a deeper understanding by posing "why" and "how" questions. In her lesson preparation, she creates slides that include relevant sources, videos, and simulations, especially when resources like microscopes are unavailable. Leyla prefers not to rely on textbooks; instead, she engages students in activities like drawing graphs or conducting simulations, stressing conceptual understanding over rote memorization. She employs a variety of teaching strategies to enhance student learning. Lastly, Leyla fosters discussions where students debate the validity of scientific findings and relate them to personal experiences and societal issues, helping them understand the relevance of science in their daily lives.

Leyla explained that she takes a flexible yet intentional approach to lesson planning, ensuring thorough preparation at the beginning of each unit. She organizes resources, learning objectives, and activities in a slide format that reflects the intended sequence for the unit, although she does not create daily written plans. Her activities range from scientific games and experiments to interactive tasks like filling in gaps or matching words, and she incorporates media such as videos and images to engage students.

Leyla critiques traditional programs as impersonal and ineffective, advocating for smaller, interactive settings where teachers can engage meaningfully with concrete examples that link abstract concepts to real-life experiences, which she considers essential for

effectively grasping and retaining material. She expresses dissatisfaction with programs that lack practical application and fail to meet the specific needs of different subjects, while facing collaboration challenges at her school due to a lack of collective motivation and senior teachers' reluctance stemming from past unproductive experiences. Despite these obstacles, Leyla remains open to new learning opportunities, particularly those that emphasize the practical application of theoretical knowledge, and values peer collaboration as crucial to her educational process. She seeks knowledgeable, honest instructors who provide clear explanations, admit uncertainties, and offer a logical framework for understanding the "why" behind concepts, avoiding rote memorization. Although she is concerned about balancing teaching and PD time, Leyla remains optimistic, hoping the PD program will encourage meaningful discussions and practical solutions.

Leyla acknowledged that even though she has encountered concepts related to the NOS during her undergraduate studies and through personal readings, she has not received specific formal education on the topic. She believes that in science education, NOS is often taught implicitly, with little emphasis on its key components. She points out that while the curriculum includes some aspects of scientific practices, such as observation and discussion, it does not clearly convey the evolving nature of scientific knowledge. For example, the reclassification of Pluto from a planet to a dwarf planet presents an opportunity to discuss how scientific knowledge can evolve; however, such topics are seldom emphasized. Overall, Leyla felt that teaching about NOS is too implicit and should be made more explicit, especially for younger students who struggle with critical thinking and evaluation.

Case 5: Melisa. Melisa graduated from a public university with a degree in Science Education. She was in her ninth year of teaching and had been assigned to a public school about two years after her graduation. Currently, she was pursuing a master's degree in Comparative and International Education at a public university and was in the thesis stage of her studies.

Melisa works at a relatively small school with a medium socio-economic profile that is above average. Due to the limited physical environment, characterized by small classrooms, Melisa adapts her teaching practices accordingly. She focuses on fostering critical thinking through questioning and providing worksheets to challenge students, rather

than relying on hands-on experiments or group activities due to space constraints. She emphasizes the importance of asking good questions and encourages students to formulate their own questions instead of concentrating solely on answers. Although the school lacks a laboratory and the classrooms are small, they are equipped with smart boards and internet access, which Melisa utilizes for teaching, particularly through the EBA platform.

Melisa is actively engaged in various PD activities. That year, she participated in the "Applied Science Workshop" and took online courses, attending conferences whenever her schedule permitted, such as the "Design Geometry" and the "Change in Education" conference. Additionally, she took part in in-service training offered by MoE. She regularly applied for online in-service training provided by MoE, as face-to-face options are rare. Regarding the effectiveness of PD programs, Melisa emphasized the importance of having a knowledgeable and well-prepared trainer. She finds workshops where she can interact with the trainer and apply what she learns to be the most beneficial. For instance, a design-thinking workshop organized by MoE, featuring instructors from Stanford, provided a rich learning experience through hands-on activities, feedback, and opportunities for improvement. Melisa feels that programs lacking chances for practical application or adequate preparation are less effective. She emphasizes the need for workshops where she can apply what she learns and receives guidance from the instructor. When it comes to collaborative work with colleagues, Melisa expresses frustration over the lack of cooperation at her school. Her colleagues generally show reluctance to engage in collaborative efforts, and most of her initiatives are carried out independently. She has few opportunities to collaborate with teachers from other subjects, and even within the science department, her ideas are often met with indifference. For the PD program, Melisa's main expectations were to expand her knowledge, acquire practical tools and materials for her teaching, and benefit from the experiences and perspectives of her colleagues. However, she worried about time constraints, as balancing the demands of teaching with attending such programs is challenging. Despite this, she remained optimistic about the chance to learn and grow through the program.

Melisa's teaching approach emphasizes fostering engagement and encouraging critical thinking among her students. She typically begins her lessons by reviewing previous topics with open-ended questions, asking students what they remember or what stood out to

them, rather than merely recalling covered material. She then introduces a new topic with a thought-provoking question to capture students' attention, followed by a series of questions designed to challenge their thinking. Throughout the lesson, she promotes dialogue and uses students' responses to guide the lesson's direction. After posing questions, she often enhances her explanations with videos from the EBA platform, which help visualize and demonstrate the concepts. For assessment, Melisa does not necessarily evaluate students at the end of every lesson but employs tools like Plickers for unit reviews and student feedback via EBA to monitor learning. At the conclusion of a unit, she frequently utilizes these tools for assessment, along with reviewing textbook exercises and unit tests.

Melisa's approach to lesson planning is both relaxed and structured. While she doesn't create extensive daily lesson plans, she ensures that she remains organized and always prepared. She keeps a notebook where she records what has been accomplished in each class, any assignments given, and what needs to be addressed in future lessons. She also notes critical questions or concepts she wants to cover, often writing them on post-its and placing them in her planner for quick reference. In terms of teaching strategies, Melisa primarily uses EBA and private sources extensively to visualize concepts, especially since her school lacks a laboratory. She relies on these platforms for simulations, videos, and experiments that enhance her lessons, given that preparation time at her school is limited. Additionally, she finds Plickers invaluable for immediate feedback on student understanding, enabling her to identify which concepts require further clarification. Overall, her teaching strategy centers on inquiry-based learning, utilizing questions and dialogue to foster critical thinking and student engagement.

Melisa learns best through active engagement with the material, particularly by listening and taking notes. She finds that simply listening or reading isn't enough for her to retain information; she needs to write things down to reinforce her learning. Writing plays a crucial role in her learning process, even if it takes more time. She also emphasizes the importance of using multiple sources of information, believing that the brain benefits from diverse input. This method of combining listening, reading, and writing is something she recommends to her students as well, encouraging them to draw on various resources to enhance their understanding.

Melisa views NOS as a concept that encompasses how science operates, its processes, and the production of scientific knowledge. She has formal training in NOS from her previous studies in a master's program, during which she explored the historical development of science. Though she feels she has a foundational understanding of NOS, she believes she is still expanding her knowledge. She considers NOS essential to her teaching, emphasizing that instead of merely presenting scientific facts to students, she focuses on explaining how scientific knowledge is produced, the processes involved, and the evolution of science. In her opinion, NOS education is increasingly important in today's information age, where knowledge rapidly evolves, and various perspectives must be considered. She highlights the significance of teaching students that science is dynamic, not static, and that scientific knowledge can change over time. She feels that, in practice, teachers are limited in their ability to fully incorporate NOS, as they are often restricted to using government-mandated textbooks and constrained resources.

Case 6: Zeynep. Zeynep graduated from the Department of Science Education at a public university in 2019. She has worked at several private schools and was employed at one at the start of the PD program. Zeynep was pursuing a master’s degree in the Science Education department at a public university when the PD program began.

Zeynep works at an all-boys school that emphasizes academic success. The school utilizes private resources as supplementary materials and actively incorporates MoE resources, along with interactive activities and question banks. With a focus on academic achievement, the school has achieved impressive results. In addition to academics, it emphasizes values education, English, and extracurricular activities like cooking classes, where students learn practical skills such as making Turkish coffee and baking cakes. For science education, Zeynep's school offers a laboratory program with limited resources. Science lessons typically last four hours per week for grades 5 and 6, while some grades, such as 7 and 8, have additional hours. Although the current laboratory facilities are limited due to the school’s transition from a public to a private institution, there is optimism that the new school being built in the schoolyard will provide improved conditions. Currently, she can use the lab for only one hour each week, but she still strives to incorporate practical lessons and activities whenever possible.

Zeynep participated in various PD programs. She attended in-service training sessions organized by her school, including collaborative education seminars led by expert speakers. Zeynep is particularly interested in STEM education and attends related workshops and conferences whenever possible. She believes that PD activities should strike a balance between content knowledge and pedagogical skills. Zeynep feels that while staying updated on advancements in her field is essential, pedagogical training is equally important for effective teaching. She finds it challenging to engage with students due to generational differences and recognizes the need for ongoing pedagogical training, including psychological education on child and adolescent development. Zeynep prefers active, hands-on workshops and training sessions. She values collaborative work with colleagues, especially those dedicated to continuous improvement. Zeynep emphasizes the importance of working with motivated colleagues who are willing to put in extra effort for academic growth. She believes that team dynamics, where all members contribute enthusiastically, make a significant difference in achieving educational goals.

According to Zeynep's pre-interview, her teaching approach centers on engaging students through curiosity and exploration. She often begins lessons with intriguing examples or news items that spark interest. Rather than directly presenting information, Zeynep prefers to let students discover concepts independently, which aligns with the 5E instructional model. She encourages students to ask questions and connect the material to their own lives, enhancing engagement. Each lesson concludes with students sharing examples from their experiences that relate to the topic, fostering a deeper understanding of the material. Additionally, for the past five years, she has incorporated a unique journaling activity where students write about what they learned during the lesson in a "daily journal." At the start of the next class, she asks a few students to share their journal entries, which serves as both a review and a source of humor, as students often notice things that others missed. When preparing for lessons, Zeynep follows structured lesson plans that are frequently created collaboratively with her colleagues. These plans include links to relevant news articles, videos, and other resources for classroom use. While she adheres to the plans, she enjoys adding spontaneous ideas and content, although this can sometimes be somewhat restricted by the detailed plans. Zeynep also uses interactive websites and Web 2.0 tools, to incorporate hands-on activities and experiments into her lessons, ensuring that students actively engage with the content.

Zeynep's lesson planning process is structured and well-organized, particularly at her current private school. She employs a specific template from her school's website that adheres to the 5E instructional model, highlighting student engagement through exploration and inquiry. The planning process starts by generating student curiosity in the "Engage" phase, utilizing visuals or materials that ignite interest. These resources, along with any necessary experimental materials, are prepared in advance, sometimes even months ahead of time. At her school, all lesson plans and experimental materials for the first semester are finalized in August, ensuring smooth execution. Zeynep also integrates extracurricular activities, such as student teams like "Science Heroes," "Goodness Team," and "Origami Team," into her lessons. These teams enable students to explore their interests, and the "Science Heroes" team participates in weekly hands-on experiments. These activities are planned ahead, and Zeynep meticulously organizes the experiments with the team. For lesson activities, Zeynep favors hands-on and individual tasks for students. However, time constraints, particularly due to the curriculum, sometimes limit how much she can allow students to work independently. Despite these challenges, she strives to design lessons that offer meaningful and engaging activities, particularly during lab sessions, which are viewed as opportunities for students to develop practical skills.

Zeynep describes herself as an active learner who doesn't retain information well through passive listening. She finds it challenging to concentrate for extended periods when listening alone, which is why she empathizes with her students in the classroom. Throughout her learning journey, she has discovered that she is more effective when she actively engages with the material. For instance, in her current graduate studies, she often struggles to absorb information from lectures. To address this, she takes detailed notes, sometimes records the lecture, and then transcribes and summarizes the information. This writing and reading process helps her understand and retain the material more effectively than passive listening.

Zeynep recalls taking a course on the NOS during her studies in science education. She mentions that the course focused on helping students engage with science as scientists do by collecting data, solving problems, developing hypotheses, and conducting research. Although she doesn't remember every detail, she emphasizes the importance of encouraging students to experience science in this hands-on way. Regarding her thoughts on teaching NOS in science classes, Zeynep believes that science is more connected to everyday life than

other subjects and that concepts such as hypothesis, independent variables, and dependent variables can become more relatable through real-life examples and problems. She suggests that teaching the NOS positively influences students' attitudes toward science, which in turn affects their approach to science education. Zeynep also reflects that elements of NOS appear in the curriculum, though she does not recall specific outcomes or related terms. She thinks integrating NOS into the curriculum could enhance students' understanding and engagement with science. She adds that even though explicit references to NOS may be limited, its principles are implicitly present in many classroom activities. Therefore, she believes that making these connections more visible could strengthen both students' interest and conceptual understanding in science.

3.5. Professional Development (PD) Program

The reflective/collaborative professional development program, structured around the RFN framework, was implemented through online synchronous meetings on Zoom. The PD program lasted a total of nine weeks, with one week set aside before the implementation to inform participants about the PD program and the pre-data collection process. During the following seven weeks, science teachers were engaged in a collaborative reflective PD program. The final week was designated for the post-data collection process. Table 3.3 indicates the flow of the collaborative/reflective PD program based on the RFN framework.

The implementation of the PD program mainly focused on (1) teachers' collaborative exploration of the RFN category, (2) developing lesson plans for each category in groups, and (3) implementing their lesson plans in their classrooms and reflecting on the implementation of their classroom practices. To ensure sufficient time for implementing lesson plans before the reflection part, the third session of the workshop began the following week. The duration of the sessions varied according to their demands. For the reflection session, the duration was about 30 minutes; on the other hand, the exploration of the new category and lesson plan development took about 120 minutes separately. The goal was to conduct the first and second sessions on the same day and hold the third session on a different day.

Table 3.3. The flow of the collaborative/reflective PD program based on the RFN framework.

Time	Flow of the Program	Duration
Week 1	Conducting pre-data collection Session 1: NOS-RFN	Introduction (90')
Week 2	Session 1: Aims and values of science (AV)	Workshop 1 (120' + 120'+ 30')
	Session 2: Developing lesson plan as groups (AV)	
	Session 3: Reflection on the implementation of lesson plan (AV) (Discussion & Evaluation)	
Week 3	Session 1: Scientific methods (M)	Workshop 2 (120' + 120'+ 30')
	Session 2: Developing lesson plan as groups (M)	
	Session 3: Reflection on the implementation of lesson plan (M) (Discussion & Evaluation)	
Week 4	Session 1: Scientific practices (SP)	Workshop 3 (120' + 120'+ 30')
	Session 2: Developing lesson plan as groups (SP)	
	Session 3: Reflection on the implementation of lesson plan (SP) (Discussion & Evaluation)	
Week 5	Session 1: Scientific knowledge (SK)	Workshop 4 (120' + 120'+ 30')
	Session 2: Developing lesson plan as groups (SK)	
	Session 3: Reflection on the implementation of lesson plan (SK) (Discussion & Evaluation)	
Week 6	Session 1: Social & institutional aspects of science (SI)	Workshop 5 (120' + 120'+ 30')
	Session 2: Developing lesson plan as groups (SI)	
	Session 3: Reflection on the implementation of lesson plan (SI) (Discussion & Evaluation)	
Week 7	Session 1: Preparation of final lesson plan 1 as groups (Combining at least 3 RFN categories)	Workshop 6 (120' + 120'+ 30')
	First classroom observations (6 teachers separately)	
	Session 2: Reflection on the implementation of lesson plan (Discussion & Evaluation)	
Week 8	Session 1: Preparation of final lesson plan 2 as groups (Combining at least 3 RFN categories)	Workshop 7 (120' + 120'+ 30')
	Second classroom observation (6 teachers separately)	
	Session 2: Reflection on the implementation of lesson plan (Discussion & Evaluation)	
Week 9	Conducting post-data collection	
	Final thoughts, evaluation of the program Closing session	

After covering five categories, lesson planning, and reflection sessions, teachers worked in groups to develop two lesson plans that included at least 3 RFN categories. The researcher observed each teacher separately in their classrooms for two lessons over separate weeks. Finally, the researcher gathered post-data sources and conducted the last session to finalize thoughts for the program evaluation.

Through the workshops of the collaborative and reflective PD program, teachers explored various categories of RFN each week. The learning outcomes of each workshop are listed in Table 3.4.

In general, workshops include three sessions. The first session begins with discussions about teachers' interpretations of the related RFN category, the importance of this category in science or science lessons, and their experiences teaching it. When teachers have the chance to share their ideas and interpretations at the start of a PD program, it fosters active engagement. By participating in the discussion, teachers become more invested in the learning process, which can boost their motivation and commitment to professional growth (Guskey, 2002). Additionally, allowing teachers to express their ideas and interpretations recognizes their professional expertise. This can promote a sense of empowerment and ownership in their professional development (Wei *et al.*, 2009).

In the second part of the first session, the aim is to develop theoretical knowledge about the related FRN category through various materials such as articles, news, websites, documents, and photos that can help teachers comprehend the content knowledge regarding the related RFN category. The goal is to encourage teachers to explore independently through collaborative group studies. Incorporating active learning strategies in the program, such as group discussions and problem-solving tasks, and examining articles, aims to facilitate the application of new knowledge and skills in the classroom (Prince, 2004). Engaging in discussions about ideas and meanings fosters a collaborative learning environment. Teachers can exchange perspectives, share successful practices, and learn from one another. This collaborative approach promotes a sense of collegiality and can lead to the development of a professional learning community (Loucks-Horsley *et al.*, 1996).

In the third part of the session, teachers discuss the educational applications of the related RFN category. They review the learning goals or objectives outlined in the curriculum. Additionally, they can explore how these objectives can be taught in science lessons, considering the related RFN category. They are presented with example activities and visuals that can be used for teaching RFN. Furthermore, teachers receive example lesson plans for examining how RFN learning objectives can be integrated into lesson plans. They can work in groups and share their ideas with other groups. Studying example lesson plans exposes teachers to various teaching strategies, instructional techniques, and classroom management approaches, thereby enhancing their pedagogical knowledge (Darling-Hammond, 2006). Moreover, by examining example lesson plans, teachers gain insights into the process of curriculum planning, including aligning learning objectives, instructional activities, and assessment methods. They learn how to structure lessons effectively and sequence content to facilitate student learning. Analyzing lesson plans related to specific subject areas also helps pre-service teachers deepen their content knowledge and understand how to teach concepts effectively (Shulman, 1986). Teachers can learn how to present complex ideas, incorporate real-world connections, and facilitate student understanding.

In the second session of the workshop, teachers develop their own lesson plans considering the objectives of the school curriculum in groups. Collaborative lesson planning allows teachers to pool their knowledge, skills, and experiences. Working together on lesson plans provides opportunities for professional growth and reflection. Through discussions and feedback, teachers can refine their instructional practices, explore new teaching methods, and reflect on the effectiveness of their lessons. Additionally, teachers think critically and solve problems together. By engaging in group discussions and evaluating different options, teachers can develop their analytical skills and identify effective teaching strategies (Grossman *et al.*, 2001).

In the final session of the workshop, teachers are expected to implement their lesson plans in their classrooms. During this reflection and discussion session, teachers share aspects of their lesson plans, including strengths and weaknesses, that they experienced through the implementation process. This helps teachers evaluate the extent to which the planned activities, instructional strategies, and assessment tools align with the intended learning objectives (Larrivee, 2000).

Table 3.4. The learning outcomes of the workshops.

Workshop	Learning Outcomes
Introduction	▪ Presenting NOS as an epistemic-cognitive and social-institutional system ▪ Providing time schedule for workshops ▪ Identifying the aims and the structure of the workshops ▪ Identifying the features of collaborative working ▪ Identifying the characteristics of lesson plan development ▪ Identifying features of effective science teaching strategies
1. Aims and values (AV)	▪ Exploration of epistemic cognitive and social aims and values of science. ▪ AV triangulation ▪ Understand the educational implications of the aims and values of science in science courses. ▪ Examination of example lesson plan which the aims and values of science are integrated into it. ▪ Development of lesson plan integrating aims and values of science.

2. Scientific methods (M)	▪ Exploration of the diversity of scientific methods of science.
	  ▪ Exploration of the myth of the scientific method.
	  ▪ Brandon's matrix and gears visual
	▪ Understand the educational implications of the scientific methods of science in science courses.
	▪ Examination of example lesson plan which diversity of scientific methods of science are integrated into it.
	▪ Development of lesson plan integrating scientific methods of science.

3. Scientific practices (SP)	▪ Exploration of the diversity of different practices of science. ▪ BRH visual ▪ Understand the educational implications of the scientific practices of science in science courses. ▪ Examination of example lesson plan which integrated scientific practices of science into it. ▪ Development of lesson plan integrating scientific practices of science.
4. Scientific knowledge (SK)	▪ Exploration of the diversity of different scientific knowledge. ▪ Exploration of the myth of the scientific knowledge. ▪ Exploration the mechanism of knowledge growth. ▪ Domain specificity ▪ TLM plate ▪ Understand the educational implications of the scientific knowledge of science in science courses. ▪ Examination of example lesson plan which integrated scientific practices of science into it. ▪ Development of lesson plan integrating scientific practices of science.
5. Social-institutional system (SI)	▪ Exploration of social-institutional aspects of science ▪ SI visual ▪ Understand the educational implications of social-institutional aspects of science in science courses. ▪ Examination of example lesson plan which integrated social-institutional aspects of science into it. ▪ Development of lesson plan integrating social-institutional aspects of science.
Summary	▪ Reflecting and revising all RFN categories ▪ Evaluation of the PD program

Through the workshops, teachers were expected to collaborate and develop a deeper understanding of RFN. They are encouraged to share their ideas, resources, and experiences, and work together to create lesson plans. In this way, a learning community was aimed to be fostered. Additionally, through the workshops, various instructional techniques such as brainstorming, preparing posters, reading articles, making presentations, answering questions, whole group discussions, watching videos, creating lesson plans, and activities that promote critical thinking skills were employed.

3.6. The Implementation of Workshops

This section of the study summarizes the implementation of each workshop.

Introduction Session. The introductory session had several purposes. One of them was to help teachers get to know each other. To achieve this, the session started with a warm-up activity. Teachers were grouped into breakout rooms, where several questions were posed to encourage socializing, such as "In which district do you work? Can you give information about your school? What is the most significant challenge you face in our profession? What are your methods for overcoming these challenges? What are your expectations from other participants in this seven-week training? What are the points you aim to reach in your career in the future?" etc. Through this interaction, they met one another, learned about diverse schools, discussed other teachers' challenges, and shared their solutions to these problems.

After a brief introduction activity, teachers learned about NOS and various NOS approaches. Before presenting these approaches, a brainstorming session was held with the questions: "What is the nature of science in science education? What are the benefits of teaching the nature of science in science classes?" to facilitate discussion. Then, foundational studies on the NOS were presented, and the elements of the "Consensus approach" were introduced. Teachers critically assessed these elements from the perspective of the NOS. Following this, the "Whole Science," "Featured of Science," and "Reconceptualized Family Resemblance Approach to Nature of Science (RFN)" approaches were briefly introduced, and questions regarding the RFN approach were raised. Teachers gained insights into which RFN category they would focus on each week.

Subsequently, discussions were held on the benefits of teaching NOS and how teachers can effectively teach NOS in their classrooms. Then, the characteristics and advantages of collaborative work were listed, and teachers shared their experiences regarding collaborative work. Finally, teachers discussed and shared their experiences about effective science teaching strategies and the fundamental components of lesson plans. Emphasis was placed on the core elements of lesson planning, such as determining clear objectives, clearly writing lesson plan procedures, and providing information about the evaluation of the lesson plan.

Workshop 1 – Aims and Values of Science. Each RFN workshop includes three sections. In the theoretical section of the workshop, teachers were posed questions like, "What are the aims and values of science? What is the significance of the aims and values of science for the development of scientific knowledge? How do you make connections with aims and values in your classroom?" Teachers engaged in discussions about these questions and shared their experiences. Next, they were presented with two contrasting cases about two researchers—one who focuses on the scientific aims and values, and the other who does not. Teachers were expected to compare these two cases and determine what the aims and values of science could be. Providing two opposing cases and examples from the history of science was effective for understanding diverse aims and values. Following this, they were given examples from the history of science, each highlighting specific aims and values of science. For instance, the text on the exploration of penicillin discussed how its benefits related to "novelty" and "addressing human needs," while the text about Rosalind Franklin's contribution to the genetics development of DNA, beyond Watson and Crick, emphasized "honesty." Then, the triangle visual representing the aims and values of science, along with the table that included all epistemic, cognitive, and social aims and values, was introduced. Following that, a group activity took place. Teachers were provided with three different articles. They were asked to read their articles and discuss which aims and values of science were included in their articles within their groups. After 30 minutes, they presented their articles to other groups and shared their insights regarding which aims and values were emphasized in the articles. Other groups' teachers also provided comments on the articles. They were then asked questions about their thoughts on teaching aims and values in science education, sharing their ideas on how science textbooks, teaching programs, and science objectives incorporate these aims and values. After that, examples from the teaching

program, science textbooks, and objectives were presented to the teachers. Additionally, other example objectives, activities, and assessment tools that included the aims and values of science, developed by the researcher, were shown to the teachers. Finally, they were asked to examine an example lesson plan in their groups and discuss the questions, “Which aims and values of science were included in the lesson plan? When you consider the activities in the lesson plan, how would you evaluate them in terms of teaching the objectives and values of science?” They found the example lesson plan effective but not practical.

In the second section of the workshop, teachers were grouped in pairs based on their students’ grade level and science subject. They identified their objectives and developed their lesson plans. Afterward, they presented their lesson plans to other groups, and teachers provided feedback. This section lasted over two hours, which limited the discussion about their lesson plans. It was observed that teachers generally focused on teaching AV as only a small part of their lesson plans.

For the final reflection part of the workshop, teachers shared their experiences regarding the implementation of their lesson plans. They answered these questions: “What were the common and different experiences you encountered while implementing the same lesson plan? What could be the reason for this difference? If you were to conduct the same classroom practice a second time, would you want to make any changes to this lesson plan?” The teachers first discussed within their own groups and then all together. It was noted that teachers who are familiar with the 5E lesson plan implemented their lesson plans more effectively.

Workshop 2 – Methods and Methodological Rules. In the theoretical section of the workshop, teachers were asked questions: "What comes to your mind when you think of scientific methods? Do you think there are different scientific methods? If so, what are they?" Teachers discussed the questions and shared their experiences. Then, they were shown a diagram about the popular depiction of the scientific method (asking questions, doing background research, constructing a hypothesis, testing the hypothesis by conducting an experiment, analyzing data and drawing a conclusion, and reporting results) and asked for their ideas about this diagram. They discussed whether all scientific studies follow this diagram or not. Afterward, some concepts related to the manipulation were reviewed, and

examples were given, such as dependent, independent, and controlled variables. After that, four scientific studies from the history of science were exemplified. Teachers were asked whether these examples included manipulation, including hypothesis testing. These examples refer to diverse methods in the Brandon Matrix. Then, the Brandon Matrix was introduced to teachers, and other examples from the history of science were shown to them, and the teachers were asked to determine which kinds of scientific methods were in the Brandon Matrix. Providing many examples from the history of science was effective in terms of comprehending diverse methods. Afterward, a group activity for determining diverse scientific methods was conducted. Teachers worked in pairs and identified the scientific methods. Then, they discussed their results. They were asked what they thought about teaching methods in science education, and they shared their ideas about how science textbooks, teaching programs, and science objectives include these methods. Following that, examples from the teaching program, science textbook, and objectives were presented to the teachers. Additionally, other example objectives, activities, and assessment tools, including the M of science developed by the researcher, were shown to the teachers. Finally, they were asked to examine the example lesson plans in their groups and discuss the questions: “Which scientific methods of science were included in the lesson plan? When you consider the activities in the lesson plan, how would you evaluate them in terms of teaching scientific methods?” Using two lesson plans was effective in demonstrating how to teach diverse methods.

In the second section of the workshop, teachers were paired based on their students’ grade levels and science subjects. They established their objectives and developed their lesson plans. Afterwards, they summarized their lesson plans to other groups, and the teachers provided feedback. This section lasted over two hours, which limited discussions about their lesson plans. It was observed that teachers were significantly influenced by sample lesson plans, particularly regarding objectives and evaluations.

For the final reflection part of the workshop, teachers shared their experiences regarding the implementation of their lesson plans. They answered these questions: “What were the common and different experiences you encountered while implementing the same lesson plan? What could be the reason for this difference? If you were to conduct the same classroom practice a second time, would you want to make any changes to this lesson plan?”

The teachers first discussed within their own groups, and then all came together. For some teachers, teaching M was effective, but for others it was not. They had difficulty with time management.

Workshop 3 – Scientific Practices. The theoretical section of the workshop started with the question, "What comes to your mind when we think of scientific practices? Do you use scientific practices in your science classes?" Teachers discussed the questions and shared their experiences. Then, they were asked to watch a video from the National Research Council about scientific and engineering practices and reflect on which scientific practices they observed and the role of the teacher in the classroom. They first discussed in their groups and then as a whole. Next, teachers were informed about classification, observation, experimentation, modeling, and other components of Benzene Ring Heuristics. The analogy was explained, and it was determined that they were quite familiar with these concepts. Afterwards, they were asked questions about what they think regarding teaching SP in science education, and they shared their ideas about how science textbooks, teaching programs, and science objectives integrate SP. Following this, some examples from the teaching program, science textbooks, and objectives were presented to the teachers. Additionally, other example objectives, activities, and assessment tools that included SP in science, developed by the researcher, were shown to the teachers. Finally, they asked to examine the example lesson plans in their groups and discuss the questions, "Which scientific practices were included in the lesson plan? When you consider the activities in the lesson plan, how would you evaluate them in terms of teaching SP?"

For the second section of the workshop, teachers were grouped in pairs based on their students' grade level and the science subject. They established their objectives and developed their lesson plans. Then, they presented their lesson plans to the other groups, and teachers provided feedback. This section lasted over two hours, which limited the discussion about their lesson plans. It was noted that teachers were significantly influenced by the example lesson plans.

For the final reflection portion of the workshop, teachers shared their experiences regarding the implementation of their lesson plans. They answered these questions: "Was your lesson plan feasible? What do you think were the strengths and weaknesses of your

lesson plan? Do you think students were able to achieve the learning objectives? What were the common and different experiences you encountered while implementing the same lesson plan? What could be the reason for this difference? If you were to conduct the same classroom practice a second time, would you want to make any changes to this lesson plan?" The teachers first discussed in their own groups and then all together.

Workshop 5 – Scientific Knowledge. The theoretical part of the workshop began with the questions, "What comes to your mind when you think of scientific knowledge? Do you think there are different types of scientific knowledge? If so, what are they?" Then, teachers were shown three definitions and asked to make predictions about which concepts these definitions referred to. For each definition, an example was provided, and teachers were asked to match the definitions with the examples. Afterwards, the features of each type of scientific knowledge were explained. Next, a video about the differences between laws and theories was shown to the teachers, who then discussed the video. Some teachers had misconceptions about the function of theories and laws, which helped them comprehend better. Following that, a group activity commenced. In this activity, teachers were asked to categorize diverse scientific knowledge within their groups. Each group shared their categorization. Then, a TLM diagram was presented, illustrating how the diverse forms of scientific knowledge contribute to scientific understanding. The growth of scientific knowledge was explained in terms of paradigm shifts and collective development. The second group activity began, where teachers were tasked with developing an online poster focusing on the growth of scientific knowledge for specified issues such as atoms, the solar system, or the periodic table. Each group then presented their poster to the others. Teachers enjoyed categorizing different types of scientific knowledge and participating in the poster activity. Afterwards, they were asked questions about their thoughts on teaching scientific knowledge in science education, sharing their ideas regarding how science textbooks, teaching programs, and science objectives incorporate scientific knowledge. Soon after, some examples from the teaching program, science textbooks, and objectives were presented to the teachers. Additionally, other example objectives, activities, and assessment tools that include scientific knowledge in science, developed by the researcher, were shown to the teachers. Finally, they were asked to examine the example lesson plans in their groups and discuss the questions: "Which scientific knowledge was included in the lesson plan?

Considering the activities in the lesson plan, how would you evaluate them in terms of teaching scientific knowledge?"

In the second section of the workshop, teachers were paired according to their students' grade level and science subject. They defined their objectives and developed their lesson plans. Following this, they presented their lesson plans to other groups, and the teachers provided feedback. This section lasted under two hours, allowing for detailed feedback to be given to other groups.

For the final reflection segment of the workshop, teachers shared their experiences regarding the implementation of their lesson plans. They answered these questions: "Did you find it difficult to integrate scientific knowledge into your lesson plans? What went well during your classroom implementation? What kind of challenges did you encounter during your classroom implementation? Do you think the lesson was meaningful for the students? What were the common and different experiences you encountered while implementing the same lesson plan? What could be the reason for this difference? If you were to conduct the same classroom practice a second time, would you want to make any changes to this lesson plan? etc." The teachers first discussed within their own groups and then together as a whole.

Workshop 6 – Social Institutions and Organizations of Science. The theoretical part of the workshop started with the question, "What comes to your mind when you think of social-institutional systems of science (SI)?" After a brief discussion, teachers were grouped and asked to read articles and consider which issues could be related to the social-institutional aspects of science. After reading the articles, each group discussed and identified the issues related to the SI. They then summarized their articles for the other groups, leading to a whole group discussion. A generative image depicting SI aspects of science was shown to the teachers, with information and examples presented for each sub-category. Teachers were encouraged to provide examples for each of them. Additionally, an example from the history of science (the life of Salome Gluecksohn-Waelsch) was shared. Group activity then commenced, with teachers tasked to find a new example that included at least two sub-categories of SI. Teachers worked in pairs and then shared their findings with the other groups. Afterwards, they were posed questions about their thoughts on teaching SI in science education, and they shared their ideas about how science textbooks,

teaching programs, and science objectives incorporate SI. Following this, several examples from the teaching program, science textbooks, and objectives were presented to the teachers. Moreover, additional example objectives, activities, and assessment tools that include social-institutional aspects of science, developed by the researcher, were shown to the teachers. Finally, they were asked to examine the example lesson plans in their groups and discuss the questions: “Which SI was included in the lesson plan? How would you evaluate the activities in the lesson plan in terms of teaching the SI?”

For the second section of the workshop, teachers were paired based on their students’ grade levels and the science subjects they taught. They established their objectives and developed their lesson plans. Next, they presented their lesson plans to other groups, and the teachers provided feedback.

For the final reflection part of the workshop, teachers shared their experiences about implementing their lesson plans. They answered these questions: "Did you find it difficult to integrate SI aspects of science into your lesson plans? What went well during your classroom implementation? What kind of challenges did you encounter during your classroom implementation? What were the common and different experiences you encountered while implementing the same lesson plan? What could be the reason for this difference? If you were to conduct the same classroom practice a second time, would you want to make any changes to this lesson plan? etc.” The teachers first discussed within their own groups and then together as a whole.

3.7. Data Sources

Various data sources were used to assess the effect of an online collaborative and reflective professional development program on science teachers’ understanding and perceptions of NOS, their science teaching efficacy, their ability to transform NOS understandings into instructional practice, and their reflections on experiences related to collaborative work, as well as the learning and teaching of NOS, considering the professional development program structured by the RFN framework. Table 3.5 indicates which data sources were used in relation to the research questions, along with their data collection and analysis procedures. Each data source is described as follows:

Table 3.5. Data sources corresponding to different research questio

Research Questions	Sub-Research Questions	Data Sources	
1. How does participation in an online reflective and collaborative professional development (PD) program structured around the RFN framework shape science teachers' perceptions of the NOS?	1.1. How does the online reflective and collaborative PD program, structured by the RFN framework, influence science teachers' visual representations of NOS?	Visual Representations	Pr
	1.2. How does the RFN-based online reflective and collaborative PD program influence science teachers' perceptions of the NOS?	Individual Interview	Pr
2. How do teachers translate their NOS understanding into instructional practices after participating in the RFN-based online reflective and collaborative PD program?	2.1. How do science teachers integrate NOS-based activities into their lesson planning after participating in the RFN-based online reflective and collaborative PD program?	Individual Interview Lesson plans Teachers' journals Group discussions (Session 2)	Pr Thr A Se
	2.2. How do science teachers integrate NOS-based activities into their classroom practices after completing the RFN-based online reflective and collaborative PD program?	Interview Observation forms Teachers' journals Group discussions (Session 3)	Pr A Th
3. How do science teachers reflect on their experiences with collaborative work, as well as learning and teaching of NOS within the context of the PD program structured by the RFN framework?		Interviews Teachers' journals	Pr A

3.7.1. Visual Representations of NOS

The visual representation of NOS (see Appendix A) was used to determine the effect of an online reflective and collaborative professional development program structured by the RFN framework on science teachers' perceptions of NOS. It was conducted before and after the implementation of the PD program. The visual representation of NOS was developed by Kaya and Erduran (2018) to demonstrate how the visual tools associated with the categories of scientific knowledge and practices in NOS can be integrated into science teacher education to enhance pre-service teachers' epistemic insight. In this study, the expanded version, which includes all RFN categories—aims and values, scientific practices, scientific knowledge, methods and methodological rules, and social and institutional systems—was utilized. Additionally, after visualizing the relevant RFN category, science teachers wrote their descriptions of the visualization.

3.7.2. Individual Interview Protocols

Individual interview protocols (see Appendices B and C) served as the primary data source for this study. They were conducted with science teachers before and after the online reflective/collaborative professional development program structured by the RFN framework. Overall, the interview protocols had several purposes, including determining science teachers' perceptions of NOS, assessing how science teachers transformed their understandings of NOS into instructional practice, and exploring science teachers' views on teacher learning and the PD program.

The interview protocol conducted before the PD program consists of 16 questions. Three of them aim to gather demographic and general information about the participants. Participants were asked to provide information about themselves, including their educational background, years of teaching, school type, students, school environment, resources, materials, teaching approach, and lesson plans. Five questions were designed to gather teachers' ideas about their learning and expectations from the PD program. Four questions without sub-questions were directed at participants to determine their NOS perception and teaching of NOS. These questions were adapted and developed from the study conducted by

Kaya *et al.* (2019). Finally, participants were asked four questions to assess their science teaching efficacy.

On the other hand, the interview protocol conducted after the PD program includes additional questions to evaluate the efficacy of the program. There are four questions without sub-questions to determine science teachers' perceptions about NOS and NOS teaching. There are six questions to assess the efficacy of the PD program (translation of NOS understanding into teaching practice, experiences related to collaborative working). Finally, there are three questions to gauge science teachers' ideas about their teaching efficacy in science.

3.7.3. Lesson Plans

Through the PD program, teachers were encouraged to collaboratively develop their lesson plans by incorporating different categories of NOS. During the PD program, teachers were shown example lesson plans for various RFN categories created by Çilekrenkli and Kaya (2022) as well as by the researcher. These lesson plans were designed using the 5E model and included various RFN objectives.

The 5E instructional model was developed by Bybee *et al.* (2006) as part of the Biological Sciences Curriculum Study (BSCS). It is grounded in constructivist learning theory, which emphasizes that learners actively construct their own understanding through experiences. The model consists of five phases—Engage, Explore, Explain, Elaborate, and Evaluate—each designed to support students' conceptual development and inquiry-based learning. The structure of the 5E model encourages students to build on prior knowledge, develop scientific reasoning skills, and apply new concepts in meaningful contexts. This model has become a widely adopted framework in science education due to its effectiveness in promoting deep and lasting learning. In the current study, teachers were asked to fill in the blanks of the lesson plan format (See Appendix D). This lesson plan format was developed by the researcher to include all components of a lesson. In the lesson plan format, teachers recorded their group names, student grade levels, units, MoE objectives, and RFN objectives. Teachers formulated their RFN learning objectives based on their weekly RFN topics. In the lesson plan, they were also asked to write the lesson's prerequisites, duration,

instructional techniques, and materials they intended to use. Instructional techniques included posing questions, solving problems, hands-on activities, group work, discussions, peer explanations, project work, designing experiments, making presentations, using multimedia resources such as videos, simulations, and interactive websites, and providing students with visual and interactive representations of scientific concepts, among others. Additionally, due to time constraints, teachers were allowed to summarize their lesson plans under three headings: introduction, development, and conclusion.

3.7.4. Teacher Journals

Teachers kept journals weekly to reflect on their individual experiences regarding collaborative learning progress, the incorporation of NOS activities into lesson plans, and teaching NOS in the classroom. In total, there are 15 questions (see Appendix F). Six of these questions aimed to evaluate weekly workshops in terms of content and structure. For example, “Do you think the workshop was meaningful for you? Why do you think so? How were your group discussions during the workshop?” are two of them. The other three questions aimed to assess how science teachers incorporate NOS activities into their lesson plans. For example, “Did you have some challenges to integration of RFN to your lesson plans?” is one of the questions that aims to determine teachers’ challenges regarding the integration of RFN into their lesson plans. Finally, the last six questions aimed to gather information about teachers’ experiences teaching NOS. "Could you evaluate your teaching practice considering the weekly RFN category?” is a reflective example question that aims to evaluate teachers’ teaching practices.

3.7.5. Classroom Observation Protocols

After collaboratively developing lesson plans, teachers implemented them in their classrooms. At the end of the PD program, the researcher visited each teacher twice at their schools and observed them in action. The researcher used the Classroom Observation Protocol (see Appendix G) to evaluate how science teachers incorporate NOS activities into their instructional practices. This tool originated with 20 items and was employed in the teacher education program at Boğaziçi University, likely developed by faculty members to assess teacher candidates during their practicum. In the current study, it was adapted by the

researcher to evaluate in-service teachers' teaching practices, specifically focusing on teaching NOS. The adapted version consists of 16 items: 12 items assess teacher organization, instructional techniques, classroom management, issues related to addressing RFN, and the enactment of the designed activity, while 4 items pertain to the teacher's reflection on her implementation.

3.7.6. Group Discussions

The collaborative nature of the PD program allowed participants to work in groups and engage in intensive discussions throughout the program. For example, they discussed their interpretations of different categories of RFN, shared their experiences, and exchanged ideas on how to teach various RFN categories, select science topics for their lesson plans, and reflect on their individual experiences implementing these lesson plans in their classrooms. Group discussions served as a primary data source for the second research question, aiming to determine how the online reflective and collaborative PD program, structured by the RFN framework, affected science teachers' translation of NOS understandings into instructional practices. To achieve this, discussions during the lesson plan development session (session 2) and the reflection and discussion session (session 3) were analyzed.

3.8. Data Collection

To reach the participants, convenience sampling method was used. The professional development program was conducted via online platforms, such as Zoom. Similarly, all data (visual representations, interviews, group discussions, lesson plans) were gathered from participants through online communication tools.

At the beginning of the study, participants were informed about the aim of the study and the structure of the PD program, including its duration, workshops, reflection sessions, data collection tools, and procedures. The data collection tools were introduced to them, and their permission was obtained for voluntary participation in this study. Teachers' expectations regarding the PD program were also addressed. Additionally, the days for the workshops, reflection sessions, and classroom observation were confirmed. Before the

implementation of the PD program, teachers were involved in pre-interviews and visual representation of data sources.

Through the PD program, each week a different RFN category was covered, and teachers participated in collaborative work with their colleagues, developed lesson plans, and implemented those plans in their schools. Teachers kept weekly journals. For the reflection and discussion sessions, they shared their experiences and discussed the strengths and weaknesses of their lesson plans. Teachers' discussions were recorded as data sources. In the last two weeks, teachers developed lesson plans that included at least two RFN categories. The researcher visited the teachers in their schools and observed their implementation of the lesson plans in their classrooms. After the PD program, the researcher conducted post-interviews and created visual representations as post-data sources.

3.9. Data Analysis

The nature of the study is primarily qualitative. Therefore, the principles of qualitative research were applied. The analysis procedures for each data source are presented below.

Analysis of Visual Representations of NOS. To analyze teachers' pre- and post-visual representations, the Reflective Drawing Analysis (RDA) framework (Barak *et al.*, 2023) was applied. This approach has a qualitative nature. The RDA framework consists of three primary steps. First (1), each drawing is individually examined and described textually based on the key indicators, which include the central focus of the image(s), specific details depicted, connections among the images, and the contextual setting of the drawing. Next (2), content analysis techniques, both inductive and deductive, are employed to identify conceptual categories relevant to the study's objectives and research questions. The pre- and post-intervention visuals, along with teachers' written explanations, were compiled into a comparison table. Text excerpts were then coded by identifying key NOS concepts using the RFN framework. Finally, participants' written explanations are used to validate the findings. The qualitative data analysis was validated through two triangulation methods: investigator triangulation, involving two researchers with PhDs in science education, and data

triangulation, incorporating descriptions of the visuals and teachers' written explanations (Barak, 2014).

Analysis of Individual Interview Protocols. The analysis of interviews followed several steps. First, all pre- and post-interviews were transcribed, and all interview data was imported into the MAXQDA program. Second, an analytical plan was developed considering the theoretical framework. At this stage, open and thematic coding was applied, and major themes and codes were categorized into an initial codebook. Third, each document was read carefully, and content analysis was conducted using the initial codebook. If needed, additional codes were added, or existing ones were deleted or reorganized. In this step, memos were taken for interesting findings. Fourth, the data was evaluated based on the code outcomes, themes, concepts, and memos. In this stage, descriptive statistics and code tables were used to summarize the data. Finally, the findings were reported in relation to the research questions.

Analysis of Lesson Plans. Teachers developed lesson plans collaboratively each week. The quality of these lesson plans was analyzed using a rubric (see Appendix E) that considers the 13 criteria developed by the researcher. These criteria address both the structure of the lesson plan (explicitly stating RFN learning objectives, MoE objectives, students' prior knowledge, etc.) and the appropriateness of the lesson plan regarding the integration of the RFN framework into science lessons (appropriateness of the activity in integrating the RFN category into the scientific topic, inclusion of a variety of resources/materials incorporating technology, using various instructional techniques, and employing appropriate assessment methods, etc.). If the quality is deemed unsatisfactory, 1 point is awarded. If it is judged fair, 2 points are awarded, and if it is deemed good, 3 points are awarded. Finally, the total score for each lesson plan was calculated out of 39 points, and the developmental process of teachers was evaluated through the PD program.

Analysis of Teacher Journals. The same data analysis process used for teacher journals was also applied to the individual interview analysis. The MAXQDA program facilitated the analysis of written journals over 7 weeks. The findings were reported in light of the research questions.

Analysis of Classroom Observation. The researcher used the Classroom Observation Protocol to evaluate teachers' teaching practices. The observation protocol includes 16 items, 11 of which pertain to teaching, and 4 which focus on the teacher's reflection on their lesson practice. There are 4 options: 'Exemplary (3)', 'Proficient (2)', 'Needs Improvement (1)', and 'Unsatisfactory (0)'. The exemplary option represents that the teacher demonstrated consistent and effective skill in this area; their performance exceeded expectations. The proficient option indicates that the teacher demonstrated the skill in this area that one would expect at this level; expectations were met. The needs improvement option suggests that the teacher has the potential to demonstrate skill in this area, but more practice is needed. Finally, the unsatisfactory option illustrates that the teacher has not developed the skill and that significant improvement is required. Thus, the total score of Classroom observation ranges from 0 to 48. While reporting the findings of the observation, the researcher's notes were also taken into account.

Analysis of Group Discussions. Audio or video recordings were transcribed for the lesson plan development sessions (session 2) and the discussion and reflection sessions (session 3) through the PD program. Additionally, detailed memos were taken. After transcribing the group discussions, the data was exported to the MAXQDA program, and the findings were reported for each case separately, considering the research questions.

For the analysis of the second session, two themes were determined. The first one was "NOS integration and alignment." This theme encompasses how teachers selected and incorporated NOS learning outcomes into their lessons. It includes examining whether the specific methods used to integrate NOS into the lesson (e.g., throughout the lesson plan, specific activities, or select sections) were appropriate for teaching NOS. The second theme was "Teaching strategies and assessment." This theme focuses on the pedagogical approaches and evaluation methods employed by teachers. It covers the selection of teaching methods and their effectiveness in conveying NOS and how teachers assessed NOS learning outcomes, including whether these outcomes were explicitly evaluated. Finally, teachers' translation of NOS understanding into lesson plans was determined.

For the analysis of the third session, three themes were identified. The first theme was "Strengths and limitations of lesson plan design." This theme focuses on identifying the

effective and ineffective elements of lesson plans, such as clarity of objectives, alignment with NOS learning outcomes, and engagement strategies, highlighting what works well and what needs improvement. The second theme was “Factors explaining varied experiences within groups.” This theme examines the underlying causes of diverse experiences among members of the same group, including differences in individual teaching styles, group dynamics, and varying levels of engagement during collaborative discussions. The third theme was “Recommendations for enhanced implementation.” This theme centers on actionable suggestions to improve the execution of lesson plans, such as strategies for better NOS integration, refined teaching methods, and more effective group collaboration practices. Finally, the teachers’ translation of NOS understanding into teaching practice was identified.

3.10. Threats to Reliability/Validity/Trustworthiness

For qualitative studies, because human behavior is not static and personal experiences change from one to another, there can be numerous interpretations of the same data. Thus, there are concerns about reliability, validity, and trustworthiness.

The reliability of qualitative research refers to “whether the results are consistent with the data collected” (Merriam and Tisdell, 2015, p.250-251). Therefore, dependability or consistency terms are suggested to be used instead of reliability (Lincoln and Guba, 1985). In this study, for consistency, a suitable database was created, and a study was prepared to guide the researcher by recording all the procedures for repeating the research in the future (Yin, 2003).

Internal validity is another concern that refers to how research findings align with reality. However, because qualitative data always need interpretation, “validity must be assessed in terms of something other than reality itself” (Merriam and Tisdell, 2015, p.242). Therefore, the term credibility will be used, which represents that the “findings are credible, given the data presented,” as Lincoln and Guba suggested (1985). Yin (2003) recommends conducting cognitive mapping and explanation building through the data analysis process for internal validity. In the current study, the analysis process was reported clearly to

demonstrate how the researcher arrived at the results and how she presents the evidence for her deductions.

External validity is another concern that refers to the extent to which one study's findings can be applied in other contexts (Merriam and Tisdell, 2015), meaning how generalizable the results are. Merriam and Tisdell (2015) criticize the notion of 'generalizability' in qualitative research, interpreting it as pertaining to experimental and correlational designs. Because qualitative studies often involve single or small, non-random, and purposeful samples aimed at understanding specifics in depth, generalizability cannot hold the same meaning as it does in quantitative research. Therefore, the term 'transferability' will be used to refer to the generalizability of inquiry, which denotes case-to-case transfer (Tobin and Begley, 2004). In the current study, thick descriptions were provided to enable readers to transfer the findings to their own context (Nowell *et al.*, 2017).

In this study, to enhance the consistency, credibility, and transferability of the research, the researcher paid attention to employing triangulation, peer examination, providing thick descriptions, and disclosing the investigator's position (Merriam and Tisdell, 2015). Triangulation was achieved by utilizing multiple methods, data sources, and investigators to confirm emerging findings. Peer review occurred through discussions of the results with colleagues familiar with the framework and the field. Additionally, the research offered rich descriptions by contextualizing the study, allowing other researchers to align their contexts and transfer the findings.

The concept of 'trustworthiness' pertains to establishing the principles of consistency, credibility, and transferability throughout all stages of the research. According to Merriam and Tisdell (2015), while there may be numerous policies, guidelines, and codes of ethics, actual ethical practice ultimately hinges on the individual researcher's own values and ethics. In the current study, during all stages, including participant selection, data collection, data analysis, and dissemination of findings, the researcher remained attentive to their own sensitivity and values regarding issues of consistency, credibility, and transferability.

3.10.1. Establishing Trustworthiness in Data Sources Analysis

To ensure the trustworthiness of data sources, careful attention was paid to reliability, internal validity, and external validity, operationalized as consistency, credibility, and transferability, respectively.

To establish the consistency of each data source, a reliability study was conducted with an expert familiar with the RFN approach. For the visual representation data, the analysis procedures for Reflective Drawing Analysis were discussed with the expert. The expert was asked to analyze all visual representations from one case, providing detailed explanations for each. The codes and memos generated from both the researcher's and expert's analyses were compared, and after reaching a consensus, a consistency ratio of 88% was achieved.

For the individual interviews, a consistency study was conducted on one case's pre- and post-interview data. The interview questions and responses were categorized according to the research questions. The RFN expert independently analyzed the pre- and post-interviews, identifying codes and themes that aligned with the research questions. The researcher and expert then met to discuss their findings, resolving discrepancies through consensus. This process resulted in a consistency ratio of 90%.

For the teacher journal data, seven weeks of journal entries from one case were provided to the expert. The journal prompts were organized into three groups to capture teachers' experiences across workshop sessions. The expert analyzed the entries, and the researcher and expert compared their codes and themes, achieving a consistency ratio of 86%.

For the lesson plan data, an expert evaluated seven lesson plans from one teacher using the Lesson Plan Assessment Rubric. A comprehensive table was created to document the scores for each rubric item across all seven lesson plans, along with the expert's explanatory notes for scoring decisions. The consistency ratio between the researcher's and expert's evaluations was 95%.

For the observation data, the researcher used the Observation Rubric, along with audio recordings and field notes. For the consistency study, the transcription of one case's lesson audio was given to the expert, who assessed the lesson using the criteria from the observation form. The researcher and expert compared their evaluations, achieving a consistency ratio of 90%.

For the group discussion data, transcriptions from one case's lesson planning sessions and reflection/discussion sessions over one week were provided to the expert. The expert evaluated the discussions based on predetermined themes and reported their findings. The researcher and expert discussed the results, reconciling differences to achieve a consistency ratio of 88%.

To ensure the credibility of data sources, triangulation was employed for each research question. By integrating diverse data sources, such as observation forms, interviews, teacher journals, and group discussions, more reliable and robust findings were obtained. Additionally, findings were presented in detail, supported by code tables and direct quotations, which provided transparent evidence of how conclusions were reached. Furthermore, the use of structured tools, such as the Lesson Plan Assessment Rubric and the Observation Rubric, facilitated consistent and objective evaluations. A pilot study was also conducted to evaluate the suitability of data sources in assessing the intended constructs. This process led to the revision of specific items, question structures, and the overall design of the instruments, ensuring greater alignment with the research objectives. These refinements enhanced the trustworthiness and reliability of the study.

To enhance the transferability of the study, triangulation was used by integrating multiple data sources, including observation forms, teacher interviews, group discussions, and more. Participants were purposefully selected to represent diverse school types (e.g., public, private, and vocational schools), various regions of Istanbul, and a range of teaching experience levels. Each teacher's lessons were observed twice in different classrooms to capture variability in teaching contexts. The findings were reported in detail, including comprehensive profiles of the teachers. This thorough description of the study's context and methodology enables educators and researchers to adapt and apply these findings and data collection tools to various educational settings.

3.11. Ethical Considerations

Ethical issues were addressed at each stage of the study, as Creswell (2018) suggested. Before conducting the study, permission regarding the appropriateness of the study was obtained from the FMİNAREK/SBB Ethics Sub-Committee of Boğaziçi University to ensure that this study would not harm the researchers, the welfare, respect, human rights, and confidentiality of research subjects, as well as the reputation of the Institute for Graduate Studies in Social Sciences as a center for properly conducted, high-quality research (see Appendix I).

At the beginning of the study, participants were informed about the study's purpose, and they could leave whenever they wished; they signed the consent forms voluntarily. During the data collection process, emphasis was placed on building trust and avoiding deception by steering clear of leading questions, withholding personal impressions, and disclosing sensitive information (Creswell, 2018). In the data analysis and reporting process, attention was given to reporting contrary findings, respecting participants' privacy, avoiding falsifying findings and conclusions, and using language appropriate for the audience. Finally, during the publication process, careful consideration was given to sharing data with others and practical results with participants.

The studies signify that there is some bias regarding being an insider researcher, such as role duality, neglecting specific routine behaviors, making assumptions about the significance of events without seeking clarification, assuming knowledge of participants' perspectives and issues, and participants assuming that the researcher already possesses their knowledge. Additionally, proximity to the situation can impede a comprehensive understanding (Sikes and Potts, 2008; Unluer, 2012). To eliminate bias as an insider researcher, the following strategies were employed (Laser, 2010):

- Reflexivity: Engage in self-reflection to recognize and critically assess your own biases, values, and assumptions. Regularly question and evaluate how your role as an instructor or researcher may influence your perspective.

- Triangulation: Utilize multiple sources of data, such as interviews, observations, and document analysis, to validate and cross-check findings. This approach helps mitigate the risk of relying solely on your own interpretations.
- Participant Validation: Solicit input and feedback from participants regarding your understanding and interpretations of their experiences. This practice ensures that you accurately represent their views and avoids the assumption that you know everything.
- Member Checking: Share your initial findings and interpretations with participants to validate their accuracy and capture any discrepancies or additional insights they may provide.
- Peer Debriefing: Engage in discussions with fellow researchers or mentors who are external to the study. Their input can offer alternative perspectives and challenge potential biases.
- Maintaining Boundaries: Establish clear boundaries between your roles as an instructor and a researcher. Be aware of the potential impact your dual role could have on your objectivity and be transparent about your intentions with participants.
- Bracketing: Acknowledge and temporarily set aside any preconceived notions and assumptions during data collection and analysis. This promotes a more open-minded approach and encourages the exploration of diverse perspectives.
- Continuous Learning: Cultivate an attitude of curiosity and openness to continually learn from participants, the literature, and the research process itself. Actively seek clarification, ask probing questions, and challenge your own assumptions.

3.12. Pilot Study

In this section, the information about the implications of the pilot study, the findings of the pilot study, and the researcher's reflections on the pilot study is presented.

3.12.1. Participants of the Pilot Study

The pilot study involved four participants with diverse demographic characteristics. Erica and Hailey, both holding BA degrees, have teaching experience of 12 years and 9 years, respectively, and work in public schools. Gloria, an MA student with 7 years of experience, teaches in a public school. Olivia, a Ph.D. student with 4 years of experience, is

employed in a public school. All participants are affiliated with public schools across different districts in Istanbul, reflecting a range of educational levels and teaching experiences, as shown in Table 3.6.

Table 3.6. Demographic information about the participant in the pilot study.

Case ID	Participants' Nick name	Educational Level	Serving Year	School Type	Pre-NOS Learning Experiences
1	Erica	BA degree	12	Public	Not taken NOS course
2	Hailey	BA degree	9	Public	Not taken NOS course
3	Gloria	MA student	7	Public	Not taken NOS course
4	Olivia	Ph.D. student	4	Public	Not taken NOS course

3.12.2. Implementation of the Pilot Study

The pilot study was conducted over four weeks, with one week allocated for pre-data collection, two weeks for implementing a professional development (PD) program focused solely on two RFN categories: M and AV, and one week for post-data collection. The study involved four science teachers selected through convenience sampling.

The schedule for the pilot study is presented in Table 3.7. During the first week, the participants were informed about the program's flow, data sources, and pre-data collection. Individual pre-interviews were conducted via ZOOM. Additionally, teachers were asked to create visual representations of the RFN categories and explain their illustrations.

In the second week, three sessions were conducted. The first session (Introduction) involved teachers introducing themselves and engaging in discussions about the definition of NOS. They were introduced to the RFN framework, its categories, and the benefits of teaching the NOS to students in science lessons. The characteristics of scientists were also discussed. However, after the pilot study, it was found that this workshop should aim other learning outcomes listed in Table 3.4 and be more interactive. Thus, this workshop developed later.

In the second session of the week (Workshop 1.1), teachers were asked to share their experiences regarding the AV of science. They were also meant to acquire theoretical knowledge about the AV of science and examine how these AV can be incorporated into lesson plans through the use of example lesson plans. Teachers were encouraged to actively participate in group discussions, engage in group work, and express their ideas. In Workshop 1.1, to teach AV, teachers were directly shown a table that included eleven aims and values provided by Erduran and Dagher (2016). Additionally, some examples with short descriptions and related images were provided for each AV of science. Furthermore, teachers were given two articles to examine, focusing on the related aims and values. Teachers were then asked to present their findings to another group after discussing and analyzing the articles within their own groups.

Table 3.7. Schedule of the pilot study.

Time	**Flow of the Program**	**Duration**
Week 1	Conducting pre-data collection	
Week 2	Introduction: Acquaintance, What is nature of science?	Introduction 60’
	Session 1: Aims and values of science (AV)	Workshop 1.1 90’
	Session 2: Developing lesson plan as groups (AV)	Workshop 1.2. 90’
	Classroom observation (for 2 cases)	40’ + 40’
Week 3	Session 3: Reflection on the implementation of lesson plan (Discussion & Evaluation)	Workshop 1.3. 30’
	Session 1: Scientific methods (M)	Workshop 2.1. 120’
	Session 2: Developing lesson plan as groups (M)	Workshop 2.2. 90’
	Classroom observation (for 2 cases)	40’ + 40’ + 40’
Week 4	Session 3: Reflection on the implementation of lesson plan (Discussion & Evaluation) Evaluation of the program	Workshop 2.3. 30’
	Conducting post-data collection	

In the third session of the week (Workshop 1.2), teachers were asked to develop their lesson plans. They were grouped, and some MoE objectives had been provided to them. Teachers were expected to create their RFN objectives and lesson plans, including AV of

science, and present their lesson plans to another group. The next day, teachers were to implement their lesson plans in their classes, and the researcher visited and observed two teachers during their lessons at their school.

However, it was observed that following the pilot study, teachers faced difficulties in understanding the intended AV, integrating them into their lesson plans, and teaching them effectively in their science classes. Upon re-evaluation of the workshop, it became clear that it did not sufficiently enable teachers to explore the diverse AV; instead, these AV were generally presented to them as a list. As a result, they struggled to grasp the epistemic-cognitive aims and values, as they were more familiar with the social aims and values of science. Thus, even when their science topics were more appropriate for teaching epistemic-cognitive AV, they preferred to integrate the social AV into their lessons.

As a result, some changes were made following the pilot study. In the new version, teachers were first provided with two cases of scientists: one who paid attention to the AV during their studies and the other who did not. Teachers were asked to evaluate and discuss these two cases, considering the aims and values of science. Historical cases were then presented for each aim and value. Additionally, teachers were encouraged to engage in deeper thinking on AV and help internalize their understanding by evaluating the historical cases while considering the AV. Next, a group activity analyzing two articles related to AV was implemented. Finally, the table provided by Erduran and Dagher (2016) was presented.

Workshop 1.3 and Workshop 2.1 were held on the same day. During Workshop 1.3, teachers were asked to reflect on their experiences within their own groups and then share their reflections with other groups through guided questions. Afterward, Workshop 2.1 commenced with the goal of enabling teachers to share their ideas about scientific methods, informing them about various scientific methods through collaborative activities and examples, raising their awareness of how to teach scientific methods in science lessons, and finally, examining a sample lesson plan that included scientific methods.

The following day, Workshop 3.2 took place. During this session, teachers were encouraged to develop their lesson plans and then present them to another group. It was observed that teachers had a better understanding of and integrated scientific methods with

the aims and values of science. In the same week, teachers were encouraged to implement their lesson plans in their classrooms. The researcher visited and observed three teachers during their lessons at their respective schools.

During the last week, Workshop 3.3 was conducted. Teachers were encouraged to reflect on their experiences within their own groups and share their reflections with other groups through directed questions. Following that, the two-week PD program was evaluated. In the same week, post-data sources were collected. Individual interviews were conducted via ZOOM. Moreover, teachers were asked to create their visual representations of the RFN categories and explain their visuals as post data sources.

3.12.3. Summary of the Findings from the Pilot Study

The findings were summarized with consideration of the research questions.

3.12.3.1. Results of the First Main Research Question. The first main research question was "How does participation in an online reflective and collaborative professional development (PD) program structured around the RFN framework shape science teachers' perceptions of the NOS?" To address this main research question, two sub-research questions were constructed, considering the data sources of visual representations and individual interviews. The findings of each sub-research question were presented under each case separately.

The first sub-research question aims to determine the change in science teachers' perceptions of NOS through a PD program using pre- and post-visual representations. The research question was as follows: "Q1.1. How does the online reflective and collaborative PD program, structured by the RFN framework, influence science teachers' visual representations of NOS?" The qualitative analysis of visual representations before and after the intervention, as well as written data, was presented for each case separately.

The second sub-research question aims to determine the change in science teachers' perceptions of NOS through a professional development (PD) program using pre- and post-interview questions. The research question was as follows: "Q.1.2. How does the RFN-based online reflective and collaborative PD program influence science teachers' perceptions of

the NOS?" To answer this research question, the audio recordings of pre- and post-interviews were transcribed, and a thematic analysis was conducted on the interview questions related to NOS and RFN categories, specifically AV and M.

Case 1: Erica's Perception of the AV and M Categories of RFN. The findings indicated that there is no difference between Erica's pre- and post-drawing for the aims and values category of RFN. In both visuals, the teacher drew some laboratory materials related to science. On the other hand, it was observed that there is a small difference between Erica's pre- and post-drawing for the scientific methods category of RFN. While the teacher drew some materials before the intervention as scientific methods, after the intervention, she mentioned experiment and observation, which refer to two aspects of the scientific methods.

Table 3.8. Erica's codes obtained from pre- and post- interviews.

	NOS	**Teaching NOS**	**AV**	**M**
Pre-Interview	Essence Main theme	Curriculum should include NOS. Need for holistic teaching Not emphasizing enough in books Only in science-engineering section of the books. Not explicit examples	Aim- reasons for conducting studies. Values- ethical norms	Science research steps (identifying problems, defining problems, constructing hypothesis, gathering data, evaluating data, reaching conclusion, interpreting conclusions) Teaching M while making experiments.
Post-Interview		Should be taught in lessons. Should be integrated in lessons. Not emphasizing directly and explicitly. Should be taught considering students' grade levels (exp. teaching manipulation in 8th grades)	Serving to humanity Ethic norms Social dimensions Honesty Reliability	Science research steps (Identifying problems, defining problems, constructing hypothesis, gathering data, evaluating data, testing hypothesis, reaching conclusion, interpreting conclusions, generating theory/law)

The codes obtained from the questions are shown in the following table. It was found that Erica's perception changed little regarding the AV of science. She mentioned some extra codes, such as serving humanity, honesty, reliability, etc.; however, her perception of scientific methods did not change. She still thought that scientific methods were step-by-step processes.

In summary, considering two data sources, it can be concluded that the online reflective/collaborative professional development program structured by the RFN framework did not change teacher Erica's perception of the AV and M categories of RFN. Teacher Erica's awareness may have increased regarding the issues concerning RFN, but she did not internalize them.

Case 2: Hailey's Perception of the AV and M Categories of RFN. The findings of the first sub-research question (Q.1.1) showed that there is a medium difference in Hailey's pre- and post-intervention drawings for the AV category of RFN. Before the intervention, she perceived AV as developing thinking skills and attaining true knowledge; after the intervention, she mentioned novelty, accuracy, and producing knowledge. It was observed that there is a medium difference in Hailey's pre- and post-intervention drawings for the scientific methods category of RFN. Before the intervention, she perceived M as step-by-step scientific processes; however, after the intervention, she focused on constructing hypotheses, making observations, investigating, and manipulation (see Figure 3.4).

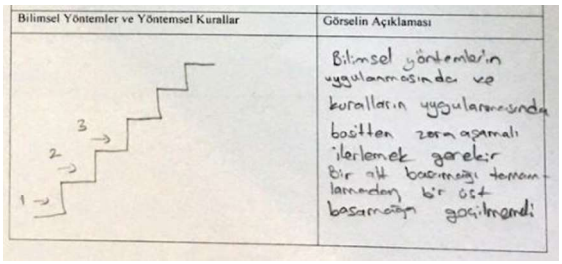
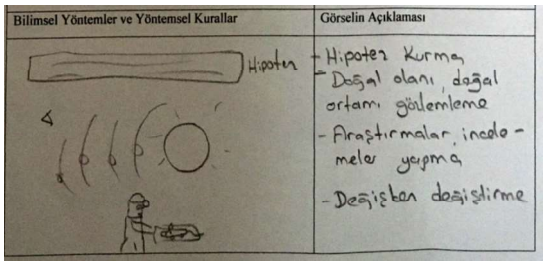
Pre-intervention	**Post-intervention**
	

Figure 3.4. Hailey's pre-and post-visual representation for M of RFN.

The codes obtained from the pre- and post-interview showed that Hailey's perception of the aims and values of science did not change; however, her perspective on scientific methods did. Although she still believed that scientific methods are step-by-step processes, she mentioned various scientific methods, including experimental and observational.

Table 3.9. Hailey's codes obtained from pre- and post- interviews.

	NOS	Teaching NOS	AV	M
Pre-interview	Analyzing Making inferences Solving environmental problems Come up with solutions.	Not possible for secondary graders Some emphases should be done. Referring some science processes skills in lesson books (such as constructing hypothesis)	No idea No teaching AV Can be taught while reporting experiments	Making investigation Questioning Analyzing Gathering data Not teaching explicitly in lessons
Post-interview		Should be taught in lessons. Making sense of content knowledge Might reinforce long term learning. Not integrated in science lessons/books Possible to teach.	Understanding the process of SK development Understanding the process of dissemination of SK Understanding the process of opposite ideas in science Behaving students as scientists. Mentioning the development process of SK.	Experimental and observational methods Investigations Interviews Searching Doing homework about investigations. Discussing the findings in classrooms.

Based on the findings of two sub-research questions, it can be concluded that the online reflective/collaborative PD program structured by the RFN framework has limitedly changed teacher Hailey's perception and visualization of NOS in two categories of RFN.

Case 3: Gloria's Perception of the AV and M Categories of RFN. There is no difference between Gloria's pre- and post-drawing for the aims and values category of RFN. In both visuals, the teacher focused on the same code, which is serving humanity. On the other hand, it was observed that there is a small difference between Gloria's pre- and post-drawing for the scientific methods category of RFN. Although the teacher illustrated Brandon's diverse scientific methods in her post-visual, she took similar notes that refer to step-by-step scientific processes (see Table 3.6).

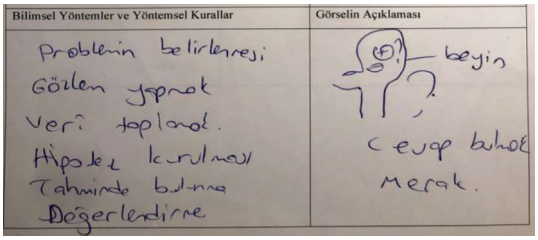
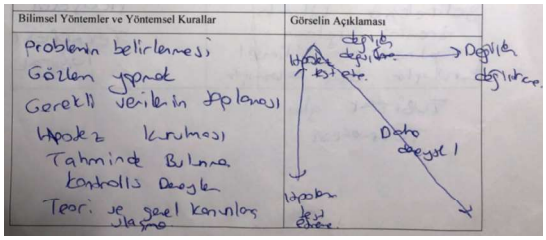
Pre-intervention	Post-intervention
	

Figure 3.6. Georgia's pre-and post-visual representation for M of RFN.

It was found that Georgia's perception changed little regarding the aims and values of science and moderately for scientific methods. She mentioned various aims and values, such as serving humanity and reaching scientific knowledge, among others. Although she still referred to some step-by-step research processes, she discussed different scientific methods, including experimental and observational, and mentioned Brandon's matrix.

Table 3.10. Georgia's codes obtained from pre- and post- interviews.

	NOS	Teaching NOS	AV	M
Pre-interview	Space Innovations Technology Science Investigations The proves of making scientific investigation.	Not teaching for due to workload Limited emphasis in curriculum (variables) More emphasis in science application course	Not teaching in science lessons Mentioning some activities.	Science process steps Mentioning while reading some text in lessons books
Post-interview		NOS should be taught. Not integrated in curriculum Including only science process skills Possible to teach NOS some degree.	Reaching scientific knowledge Making investigation about universe Serving to humanity Producing knowledge Can be taught by participating some projects (Technofest) Emphasizing AV in activities	Science process steps (Identifying problems, defining problems, constructing hypothesis, gathering data, generating theory/law) Can be taught by Brandon's matrix. (Expecting students to hypothesis testing, manipulation)

In summary, it can be concluded that the online reflective/collaborative PD program structured by the RFN framework changed teacher Georgia's perception of NOS in two categories of RFN to a limited extent. Her perception of scientific methods developed moderately.

Case 4: Olivia's Perception of the AV and M Categories of RFN. There is no difference between Olivia's pre- and post-drawing for the aims and values category of RFN. Before the intervention, she focused on some scientific practices. After the intervention, she took notes on investigation and objectivity in knowledge sharing. On the other hand, it was observed that there is a small difference in Olivia's pre- and post-drawing for the scientific methods category of RFN. After the intervention, she mentioned experiments and observations, which refer to two aspects of the scientific methods.

The codes from the pre- and post-interviews are presented in Table 3.11. It was found that Olivia's perception remained unchanged regarding the aims and values of science, and changed moderately concerning scientific methods. She identified various scientific methods as experimental and observational.

Table 3.11. Olivia's codes obtained from pre- and post- interviews.

	NOS	**Teaching NOS**	**AV**	**M**
Pre-interview	Tentative nature of SK Objectivity Subjectivity Theory leadenness Cumulative nature of science Universality Searchable Repeatable	Teaching cumulative nature of SK Teaching tentative nature of SK Teaching all scientific studies do not based on experimentation.	Making explanations Being repeatable in controlled conditions Exploring new things Serving to humanity Developing a product Ethical norms Do not harm environment/living things. Do not plagiarize. Subjectivity	Making experiment Making observation Modelling Searching Making investigation Analyzing data Questioning Teaching by making investigations
Post-interview		Possible to teach NOS. Enabling to develop science process skills. Enabling to eradicate bias towards science. Teaching diverse methods	Subjectivity Objectivity Ethical norms Sharing knowledge Nor changing data Can be taught while mentioning scientists.	Changing variables Gathering data Sharing findings Constructing hypothesis Testing hypothesis Prediction Inferences Making experiments and observations.

Considering the findings of three sub-research questions, it can be concluded that the online reflective and collaborative professional development program structured by the RFN framework changed teacher Olivia's understanding, perception, and visualization of NOS in two categories of RFN to a limited extent. Her perception of scientific methods developed moderately.

It can be concluded that the PD program was not successful in developing teachers' comprehension of aims, values, and scientific methods as planned when considering four cases. Therefore, some revisions were made to the workshops to improve teachers' understanding, perceptions, and visualization of NOS.

3.13.3.2. Results of the Second Main Research Question. The second main research question was "RQ2. How do teachers translate their NOS understanding into instructional practices after participating in the RFN-based online reflective and collaborative PD program?" For this main research question, two sub-research questions were constructed, considering the diverse data sources.

The first sub-research question of the second main research question was "How do science teachers integrate NOS-based activities into their lesson planning after participating in the RFN-based online reflective and collaborative PD program?" Four data sources (interviews, teachers' journals, lesson plans, and group discussions) were analyzed to answer this sub-research question.

The second sub-research question of the second main research question was "How do science teachers integrate NOS-based activities into their classroom practices after completing the RFN-based online reflective and collaborative PD program?" Four data sources (interviews, teachers' journals, observation forms, and group discussions) were analyzed to answer this sub-research question.

For the pilot study, the results of the sub-research questions of the second main research question were reported together for two workshops separately as groups. The next paragraphs present the findings of teachers' transitions of AV understanding into their instructional practices.

At the AV workshop, two groups worked separately to design and implement lesson plans. Group 1 (Hailey and Georgia) and Group 2 (Erica and Olivia) developed their individual lesson plans and executed them in their schools during the same week. The researcher conducted classroom observations, focusing on one teacher from each group (Hailey for Group 1 and Erica for Group 2). Their lesson plan creation and teaching practices were assessed using various data sources, including interviews, teacher journals, observation rubrics, and group discussions, with results presented distinctly for each group.

Group 1: Lesson Plan Development and Classroom Practices. Hailey and Georgia collaboratively developed a lesson plan for fifth-grade students, focusing on the topic of light reflection. Hailey's classroom implementation was observed. The lesson plan emphasized social aims and values, such as respecting evidence-based ideas regardless of their source and valuing diverse perspectives in science. They incorporated a variety of activities, including extensive question-and-answer sessions, a video presentation, small-group tasks, and peer review.

Analysis of the lesson plan revealed an explicit intent to address NOS objectives during the activities; however, these objectives were not assessed in the evaluation component. Specifically, the accompanying worksheet lacked questions related to NOS concepts. The lesson plan received a score of 25 out of 33 points on the assessment rubric.

In terms of classroom practices, Erica faced challenges with classroom management and adhering to the lesson plan as designed. Her large class size hindered effective management of group discussions, and students seemed unfamiliar with collaborative discussion formats. While Hailey made some references to NOS concepts, these were limited and not consistently integrated with the science topic. Her observation score was 55 out of 75 points.

Insights from teacher journals and group discussions revealed that both teachers struggled to internalize the AV category of NOS. These findings prompted the researcher to revise the workshop's examples, content, and structure to better support teachers' understanding and application of this category.

Group 2: Lesson Plan Development and Classroom Practices. The second group selected a 7th-grade science topic on recycling. They effectively integrated NOS objectives into their lesson plans. Teacher Erica's implementation was observed.

The NOS objectives included generating new ideas about the effective use of resources, providing suggestions for their effective use, collecting and analyzing data, conducting research, sharing data, evaluating, and discussing data on recycling studies and practices in our country. In the introduction, students view compelling images of waste to spark discussion about its causes, solutions, and the concept of recycling, addressing questions regarding recyclable materials, facilities, and their uses in Turkey. The development phase involves watching an informative video that shares collected data and discussing the importance of recycling, revisiting the same key questions to deepen understanding. In the conclusion, students propose projects to promote recycling, present their drafts to the class for discussion, and reflect on the role of idea generation in science, emphasizing creativity and collaborative idea sharing.

The classroom observation indicated that Teacher Erica was very effective in managing discussions and providing clear explanations. She encouraged her students to develop their ideas and informed them before the lesson to research the issue. She struggled with time management, resulting in only 2 or 3 groups presenting their project drafts and a limited emphasis on NOS. The group discussions and teacher journals indicated that teachers avoided making explicit connections to NOS. Teacher Erica received 63 out of 75 points.

During the M workshop, two groups worked independently to develop and implement lesson plans. Group 1 (Erica and Georgia) and Group 2 (Hailey and Olivia) created their respective lesson plans and applied them in their schools within the same week. The researcher conducted classroom observations, focusing on one teacher from each group (Georgia for Group 1 and Olivia for Group 2). The analysis of their lesson plan development and classroom practices was based on multiple data sources, including interviews, teacher journals, observation rubrics, and group discussions, with findings reported separately for each group.

Group 1: Lesson Plan Development and Classroom Practices. Erica and Georgia collaborated to design a lesson plan for a sixth-grade science topic (sound and its properties). Georgia's classroom implementation was observed. In their interviews and journal reflections, both teachers emphasized the value of using the provided sample activities and lesson plans as guides. These resources helped them align their lessons with RFN objectives and develop student-centered activities. Group discussions further allowed them to assess the strengths and weaknesses of their plan, considering factors such as student profiles, the science topic, and time constraints.

The analysis revealed that Group 1 effectively articulated both the Ministry of Education (MoE) and RFN objectives. Their lesson plan integrated scientific methods with the topic through diverse resources, including technology, while promoting active student engagement. However, some procedural steps lacked clarity. The lesson plan earned 29 out of 33 points on the assessment rubric.

Classroom observations indicated that Georgia began the lesson by listing scientific methods on the board but provided limited explanations and examples. She actively engaged with student groups, answering questions, although she faced minor classroom management challenges. Students were involved throughout, formulating and testing hypotheses and sharing findings related to sound. However, references to scientific methods were minimal. Georgia's observation score was 52 out of 75 points.

Group 2: Lesson Plan Development and Classroom Practices. Hailey and Olivia collaborated on a lesson plan for an 8th-grade science topic (simple machines), with Olivia's teaching being observed. In interviews, Hailey expressed newfound confidence in designing lesson plans that incorporate NOS activities. Both teachers found the workshop valuable for understanding knowledge construction and appreciated the collaborative discussions for identifying strengths, weaknesses, and areas for improvement. However, they acknowledged that additional time for lesson plan development would have been beneficial.

The analysis indicated that Group 2 clearly defined MoE and RFN objectives and created an activity that effectively linked scientific methods to the topic. The lesson plan encouraged active student participation, with students tasked with classifying their scientific

methods across a spectrum. However, the procedural explanations required further detail. The lesson plan received a score of 30 out of 33 points.

During the observation, Olivia began the lesson with a review of previous content, utilizing effective question-and-answer techniques and visual aids on the board. She consistently referenced scientific methods, drawing from examples presented in the workshop. Olivia facilitated group work and offered constructive feedback, although she encountered challenges with time management and ensuring a deep conceptual understanding. Her observation score was 69 out of 75 points.

3.13.3.3. Results of the Third Main Research Question. The third main research question was, “How do science teachers reflect on their experiences with collaborative work, as well as learning and teaching of NOS within the context of the PD program structured by the RFN framework?” For this main research question, three data sources (interviews and teachers’ journals) were analyzed together for each case.

The diverse data sources indicated that teachers generally considered the online PD program, with its small participant group, to be highly effective. The collaborative and reflective nature of PD allowed them to engage in discussions about the AV and M categories of NOS in both small-group and whole-group settings. Group activities encouraged teachers to express their ideas, address misconceptions, and explore diverse perspectives on science. Developing lesson plans collaboratively was initially unfamiliar, as teachers typically did not create daily lesson plans or work together on such tasks. This process, however, enabled them to uncover various teaching strategies and consider how to integrate NOS concepts into their lessons. In their journals, teachers shared their experiences implementing the lesson plans, which fostered discussions on alternative instructional methods and promoted self-evaluation.

3.12.4. Researcher’s Reflection on the Pilot Study

I want to share my experiences regarding the pilot study, focusing on data collection, the implementation process, and the content of the PD program.

The program, implementation process, days, and hours, along with my expectations and the content of the PD program, were introduced to participants separately at the beginning of the study. However, more detailed information could have been provided at that time. I observed that the participant selection step is crucial. Even though I provided detailed information to all participants through ZOOM at the start of the study, they were not fully aware of my expectations. Therefore, for the main study, I allocated more time for participant selection and ensured participants' voluntary participation.

The days were arranged without any issues, and only minor changes were made. However, when working with 6 or 8 participants, there can be some challenges in arranging the program. During the first week, I scheduled a ZOOM meeting on my account, but the sessions were divided. Then, I sought assistance from a university research assistant. The breakout rooms were not recorded by the ZOOM program, so I opened a backup account and joined breakout rooms using two computers. Thus, in the main study, two assistants provided me with technical support.

For the lesson plan development sessions, the allocated time (90 minutes) was insufficient for developing lesson plans, reviewing the lesson plans of other groups, and presenting their own lesson plans to the other groups, as the teachers were not well acquainted with lesson plan development. Therefore, for the main study, the first introduction session addressed issues such as the characteristics of collaborative work, writing lesson plans, setting objectives, and focusing on important aspects while writing a lesson plan. Additionally, a lesson plan session was organized for 120 minutes.

I observed that teachers did not provide detailed reflections of their experiences in their journals, and their reflections showed inconsistencies. Consequently, I am uncertain whether they accurately implemented their lesson plans and reflected on their experiences. Therefore, for the main study, I planned to visit the teachers twice at the end of the PD.

Gathering visual representation data sources was challenging, and I was uncertain whether participants sought assistance from external resources. Therefore, for the main study, I ensured greater clarity by implementing stricter protocols to monitor data collection processes and confirm that participants relied solely on their own knowledge and

experiences. To achieve this, I introduced detailed guidelines for creating visual representations.

For the implementation of the PD program, the introduction session focused on discussing the NOS and took place in the second week. However, in the main study, I planned to conduct this session in the first week, limiting each week to no more than two sessions. Additionally, I believe this workshop can be made more interactive by including orientation activities.

I am having difficulty determining the appropriate level at which I should integrate, help, and guide the group work, specifically during the lesson plan development process. I need to pay attention to signal which issues they should focus on during the lesson plan development as we examine an example lesson plan. Furthermore, after conducting classroom observations, I am unsure whether we should review the observation form together or not.

I faced difficulty in determining the level at which I should integrate, help, and guide group work, particularly during the lesson plan development process. I decided to focus on identifying the issues they need to address while developing lesson plans as we examine an example lesson plan together. Furthermore, after conducting classroom observations, I was uncertain whether we should review the observation form together. I opted to collaborate, discussing the strong and weak aspects of their implementations.

Lastly, teachers expressed challenges in scheduling the implementation of their lesson plans within the same week. Therefore, for the main study, it was essential to allow a longer duration between the lesson plan development phase and the implementation phase. The sessions of the main study were organized to tackle this challenge, enabling teachers to effectively arrange and execute their lesson plans without feeling rushed or overwhelmed.

For the content of the PD program, the presentation on the AV category of RFN was lacking during the pilot study. The teachers were unable to fully grasp and internalize the content. They often focused on the social aims and values of science, missing a holistic

perspective. Consequently, after the pilot study, the presentation was revised and enhanced to address these shortcomings and incorporate the missing elements.

Conversely, the presentation on the M category of RFN was found to be comprehensible to the teachers. However, it is essential to ensure that the example lesson plans provided to teachers encompass diverse scientific methods, allowing for a thorough exploration of the topic. For the main study, example lesson plans for the M category of RFN were developed to help teachers gain a better understanding and appreciation of the various scientific methods available for teaching and learning.

4. RESULTS

There are three main research questions and some sub-research questions, considering the data sources used in the study. The findings for the six cases are presented individually for each main and sub-research question. Subsequently, the cases are compared with one another for each research question.

4.1. Results of the First Main Research Question

The first main research question is “RQ1. How does participation in an online reflective and collaborative professional development (PD) program structured around the RFN framework shape science teachers’ perceptions of the NOS?” For this main research question, two sub-research questions are constructed, considering the data sources, which are visual representations and individual interviews. The findings of the two sub-research questions are presented separately under this title.

The first sub-research question examines the changes in science teachers’ perceptions of the NOS that result from a professional development (PD) program. The first sub-research question is: “RQ1.1. How does the online reflective and collaborative PD program, structured by the RFN framework, influence science teachers' visual representations of NOS?” The Reflective Drawing Analysis framework (Barak *et al.*, 2023) is used to analyze visual representations. First, each drawing is analyzed separately according to four indicators: the central image, details, interactions, and context. Second, pre- and post-PD drawings and teachers’ written explanations are organized in a comparison table. Third, text excerpts are marked and coded by identifying NOS key concepts based on the RFN framework. Ultimately, the shift in teachers’ perceptions of NOS through visual representations is identified for each case, and the results are compared across cases.

The second sub-research question seeks to determine the change in science teachers’ perceptions of the NOS after the PD program, using pre- and post-interview questions. The second sub-research question of the first main research question is “RQ1.2. How does the RFN-based online reflective and collaborative PD program influence science teachers’

perceptions of the NOS?" To answer this question, the audio recordings of the pre- and post-interviews are transcribed, and a thematic analysis is conducted for the interview questions related to NOS and RFN categories. The findings are presented separately for each case and RFN category, and each case is compared with the others.

4.1.1. Results of the Visual Representations

In this section, the findings of the first sub-research question are presented separately for each case. For each case, a general summary of the participant's NOS visualization is provided first, followed by the changes in their visualization for each subcategory of RFN. To illustrate the differences in their visualization, teachers' pre- and post-visualizations, along with their explanations, are included.

4.1.1.1. Case 1 – Aylin's NOS Visualization. In her pre-visualizations, Teacher Aylin created visuals that evoked each related RFN category. However, in her post-visualization, she preferred to write key concepts instead of visualization instead of drawing them. This may be due to her advanced knowledge in post-visualization. She might have found it challenging to illustrate the components of the aims and values of science, including ethical rules, decentralization of power, service to humanity, accuracy, critical examination, and the elements of scientific practices. Teacher Aylin was not familiar with RFN before the intervention. Her pre- and post-visualizations for each category were discussed.

Aylin's Visual Representation of the Aims and Values of Science

Before participating in the PD program, Teacher Aylin drew a beaker and humans to represent the aims and values of science. The beaker represents experiments, while the group of people symbolizes scientists. This visualization appears to reflect an empirical understanding of science, rather than a holistic one that includes scientific methods beyond experimentation and observation in the laboratory. She explained her visualization by stating that science aims to develop society and is valuable for that reason. She focused on serving humanity as one of the aims of science. She described values in terms of why science is valuable, rather than as values inherent to science.

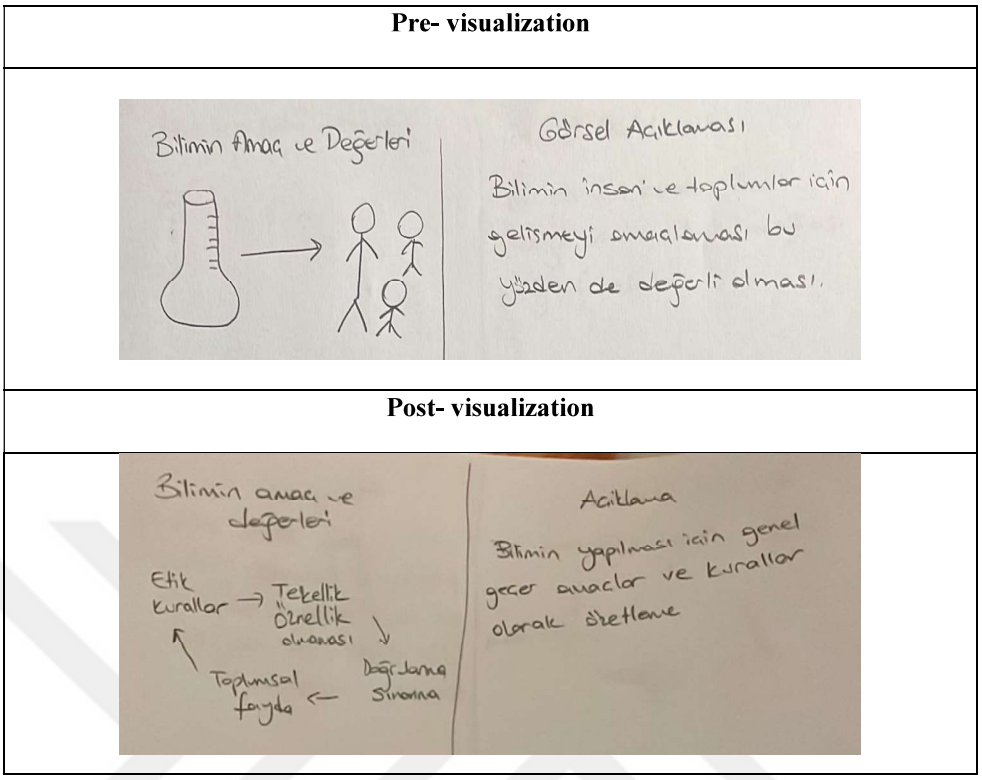


Figure 4.1. Aylin's Pre- and Post-Visualizations of the AV of RFN.

After the intervention, Teacher Aylin drew a one-directional diagram that included the concepts of ethical rules, decentralizing power, serving humanity, accuracy, and critical examination. In the PD program, these keywords were presented as real-life cases. Additionally, the table of these concepts related to the aims and values developed by Erduran and Dagher presented them without any visuals during the PD program. It was found that she referred to more concepts from Erduran and Dagher's table compared to her pre-visual. However, she did not explain these concepts in detail or provide examples of them. She likely could not internalize them. Overall, she focused on both the epistemic-cognitive and social aims and values of science. It can be said that her ideas regarding the aims and values of science have developed but still need further improvement.

Aylin's Visual Representation of the Scientific Practices

Before participating in the PD program, Teacher Aylin wrote a formula (Newton's second law of motion) for physics and a chemical equation (acid-base reaction equation) for the chemistry branch. She likely viewed scientific practices as facts and laws. In her pre-

explanation, she stated that each branch of science has diverse practices based on its nature. She emphasized the domain specificity of scientific practices in science but did not clarify the kinds of differences that exist. She might be referring to the differences in how scientific knowledge is represented.

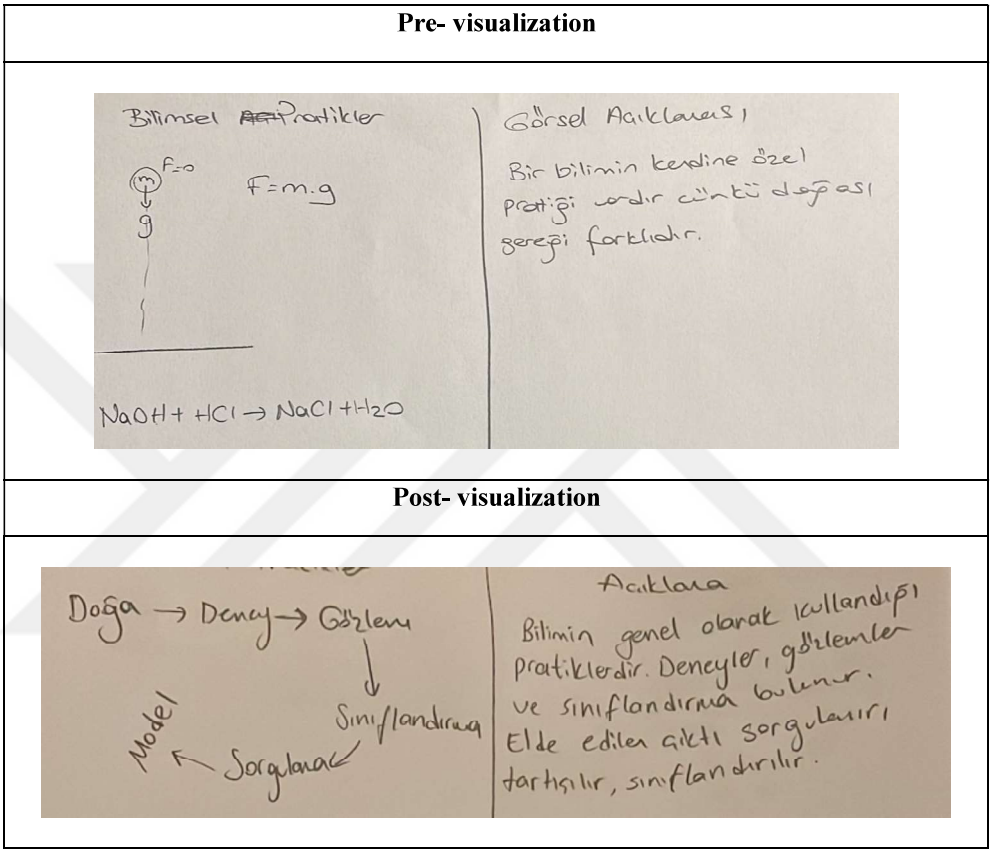


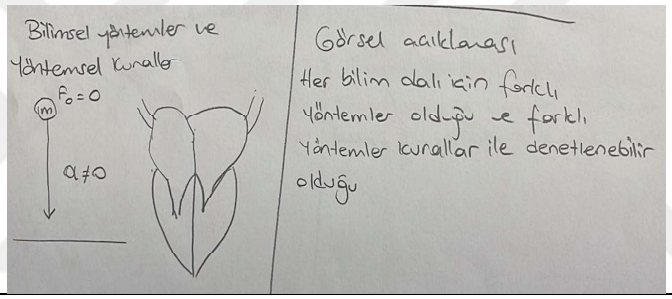
Figure 4.2. Aylin's Pre- and Post-Visualizations of the SP of RFN.

After the intervention, Teacher Aylin drew a one-directional circular diagram that included the concepts "nature, experimentation, observation, classification, questioning, and modelling," similar to Benzene Ring Heuristics. She explained her visualization by stating that scientific practices are the practices used during scientific inquiry. She also emphasized social scientific practices such as "discussions and reasoning." In the PD program, teachers watched a video about scientific practices (NGSS-scientific practices for K-12) and discussed them. Then, they discussed Benzene Ring Heuristics (BRH). It can be said that after the intervention, her perception developed, leading to a holistic understanding of scientific practices that refer to many elements in the BRH.

Aylin's Visual Representation of the Scientific Methods and Methodological Rules

Before the intervention, Teacher Aylin drew a falling mass (representing physics) and a heart (representing biology) to demonstrate the "domain specificity" of scientific methods. She explained her pre-visualization, noting that there could be "diverse scientific methods" for different branches. However, she did not specify what these methods are. She connected scientific methods to the interests of the domains, indicating that physics is a branch focused on understanding the behavior of matter, while biology concerns the functions of living tissues and organs.

Pre- visualization



Post- visualization

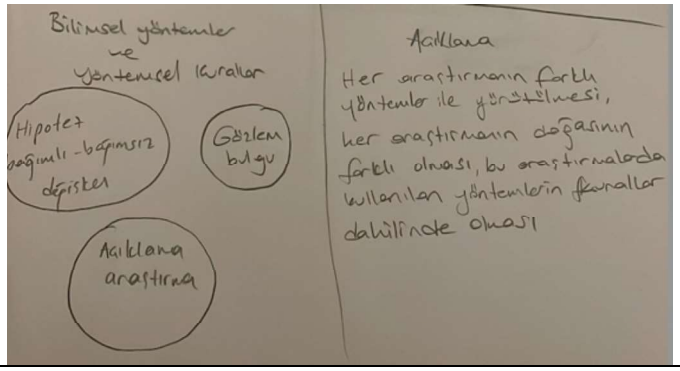


Figure 4.3. Aylin's Pre- and Post- Visualizations of the M of RFN.

After the intervention, Teacher Aylin drew three circles. The first circle included "hypothesis and manipulation," the second one included "observation," and the third included "explanation, research." She labeled "explanation" as the scientific method. Additionally, she emphasized the importance of diverse scientific methods and the domain specificity of those methods. In the PD program, teachers explored various scientific

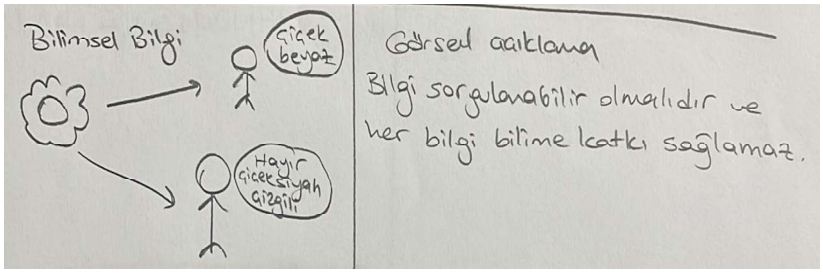
methods from the history of science, referencing the diverse methods in Brandon's matrix. Following the intervention, she could likely identify two types of scientific methods: manipulative – hypothesis testing and non-manipulative – non-hypothesis testing methods. It can be said that Teacher Aylin's perception of the scientific method category of RFN evolved after the intervention. Her post-drawing reflected an understanding that there are multiple methods in science. However, she requires a more sophisticated grasp of the diversity of scientific methods, referencing other scientific methods such as manipulative methods that do not include hypothesis testing, along with examples and more concrete explanations.

Aylin's Visual Representation of the Scientific Knowledge

Before the intervention, Teacher Aylin drew a daisy and included two people who have different comments about it. These comments are "the flower is white" and "the flower has black strips." In her pre-explanation, she signified the "interrogative nature of scientific knowledge" and highlighted that "scientific knowledge should contribute science." Teacher Aylin's drawing can be interpreted as an emphasis on the subjective nature and interpretative openness of scientific knowledge. The fact that two individuals make different observations about the same object (the daisy) illustrates that scientific knowledge is not absolute but can vary depending on the observer's perspective, background knowledge, and prior experiences. Her reference to the "interrogative nature of scientific knowledge" also highlights that science is a continuous process of questioning, reevaluating, and reconstructing knowledge rather than establishing fixed truths.

In her post-intervention visualization, Teacher Aylin depicted a "TLM" wall. Each stone of this wall represents diverse types of scientific knowledge, including theory, law, and model. She emphasized that TLM provides scientific understanding. In the PD program, this visual (a wall) served as an alternative representation for teaching scientific knowledge in science lessons. In her post-explanation, she also highlighted the differences between laws and theories. According to her explanation, laws are generally valid and proven knowledge, while theories are explanations, and models provide information about the content. It can be stated that the PD program improved her understanding of scientific knowledge.

Pre- visualization



Post- visualization

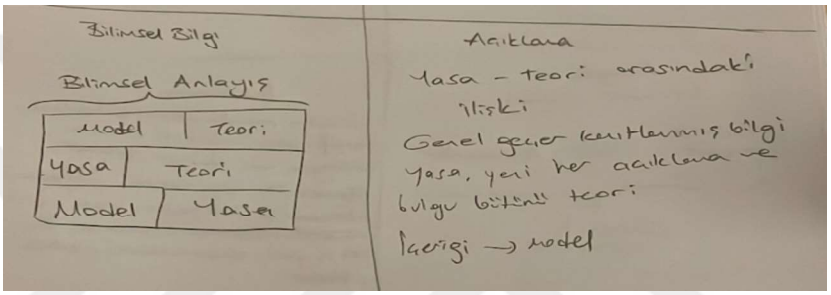
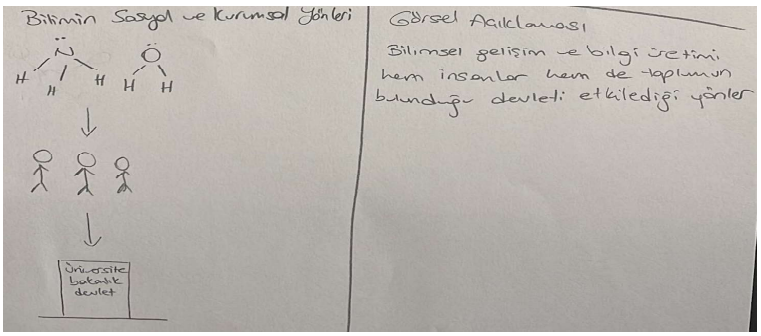


Figure 4.4. Aylin's Pre- and Post- Visualizations of the SK of RFN.

Aylin's Visual Representation of the Social-Institutional Aspects of Science

Teacher Aylin illustrated several chemical compounds, such as NH_3 and H_2O, alongside depictions of groups of people representing scientists, and symbols denoting institutions like universities, ministries, and governmental bodies in her pre-visualization. She explained that the social-institutional aspects are factors affecting society and governments. She established a connection between scientific knowledge, groups of people (scientists), and legal institutions involved in conducting scientific research. According to her visual, the development and application of scientific knowledge do not occur in isolation but are deeply intertwined with broader societal structures. She articulated the interconnections among scientific knowledge, the scientific community, and legal or institutional authorities responsible for regulating and supporting research. Through her pre-visualization, she referred to limited aspects of social-institutional systems.

Pre- visualization



Post- visualization

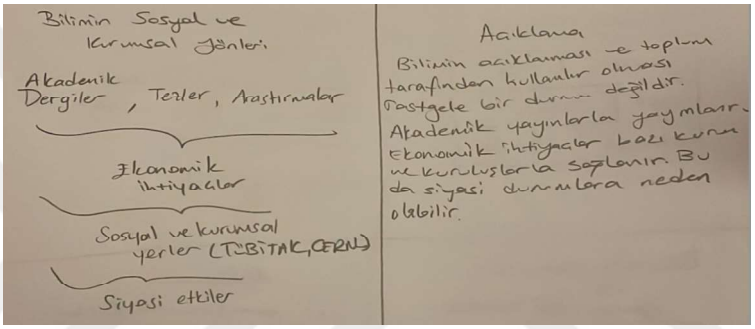


Figure 4.5. Aylin's Pre- and Post- Visualizations of the SI of RFN.

After the intervention, she deepened her understanding by incorporating concepts such as "academic journals, theses, research, economic needs, social institutions like TUBİTAK, CERN, along with political factors." In her post-visualization, she listed these concepts instead of visualizing them. In the PD program, diverse examples are provided for each sub-category of SI. Teacher Aylin can be influenced by these examples and aimed to summarize them briefly as concepts. In her post-explanation, she emphasized that scientific knowledge is published in academic journals, that there are economic needs for science, and that politics influences science. She appeared to recognize the social-institutional aspects of science and the connection between politics and science prior to the intervention. However, the pre-drawing reflects a naive perspective of this relationship. In contrast, the post-drawing indicates greater sophistication in her understanding of this relationship.

4.1.1.2. Case 2 – Beren's Visual Representation of NOS. Teacher Beren was not familiar with the RFN framework. She demonstrated a strong understanding of each category in her post visualization.

Beren's Visual Representation of the Aims and Values of Science

Before participating in the PD program, Teacher Beren drew a person with long hair and a beard. In the person's speech balloon, she wrote that you should be honest to become a scientist. This speech balloon suggested that the teacher primarily focused on the values of science when discussing its aims and values. Additionally, the teacher's pre-visualization showed that her conception of the aims and values of science was limited to "honesty." Although she used an ellipsis after her honesty advice, she did not further elaborate on the visualization. She explained her visualization by stating that the aims and values of science relate to scientists' personal characteristics, such as honesty. The teacher elaborated that she drew a bearded grandfather who is meditating. These explanations and the visualization indicated that the teacher's conception of a scientist resembles a bearded old man meditating. Teacher Beren may have drawn a connection between the values of science and meditation.

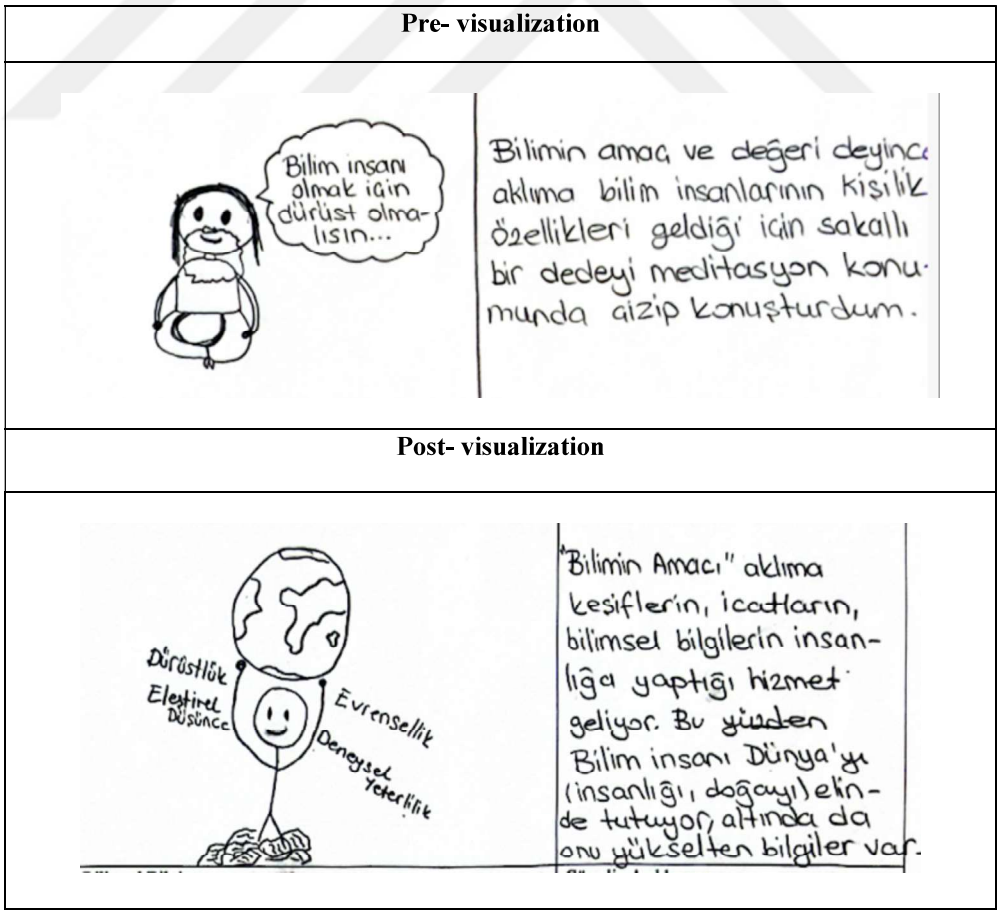


Figure 4.6. Beren's Pre- and Post- Visualizations of the AV of RFN.

After the intervention, Teacher Beren drew a person holding the world in his hands and above his head. Beneath the person, there are also various documents. In her post-visualization, the teacher added "critical thinking, universality, empirical adequacy" in addition to "honesty." In explaining the visualization, she stated that the aims of science involve serving humanity through discoveries, inventions, and scientific knowledge. She also mentioned that in her visualization, the scientist holds the world (humanity and nature) in his hands, and underneath there is knowledge that elevates it. This visualization illustrates that, with the help of the knowledge and values of science, the aim of science is to serve humanity. When compared to the pre- and post-visualizations, it can be determined that the teacher's perceptions of the aims and values of science have developed since she added more concepts to her visualization.

Beren's Visual Representation of the Scientific Practices

Before participating in the PD program, Teacher Beren drew a person who had two paths in front of her. One of the choices was the easy way, while the other was the difficult way. The person raised one arm as if to think. She also drew signboards indicating the first and second options. The teacher stated that she did not know much about scientific practices before the intervention. She indicated that the meaning of the practice suggested taking the easy way out. This explanation shows that the term for practice in Turkish created some confusion in the teacher's understanding of scientific practices.

After the intervention, Teacher Beren drew seven circles that illustrate the scientific practices such as "observation, model, data, explanation, real world, prediction, and scientific activities containing experiment, observation, and classification." Each circle in the visualization connected with two of the other practices. The teacher's post-visualization resembles the Benzene Ring Heuristics (BRH) developed by Erduran and Dagher (2014). It can be said that her understanding of the scientific practices evolved after the intervention as she learned many practices. However, she did not emphasize social scientific practices such as representation, reasoning, discourse, and social certification. When comparing her pre- and post-visualizations, it can be noted that her perception of scientific practices developed, and she referenced many elements of BRH.

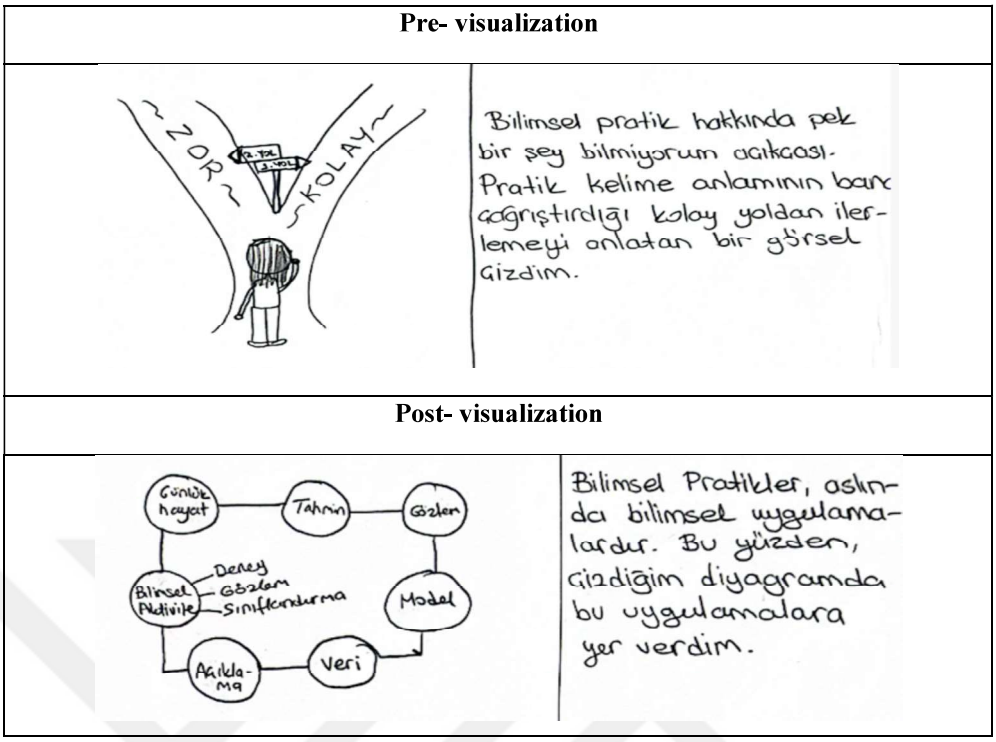


Figure 4.7. Beren's Pre- and Post- Visualizations of the SP of RFN.

Beren's Visual Representation of the Scientific Methods and Methodological Rules

Teacher Beren drew five boxes labeled with numbers and a results box in the pre-visualization. There are arrows connecting the boxes from small to big, indicating one direction. One of the arrows, however, was drawn from the larger number, five, to the smaller number, two. She stated in her explanation that scientific methods are step-by-step (the lock-step method). This is a popular misconception about the steps of the scientific method, which include asking a question, doing research, constructing a hypothesis, testing the hypothesis, analyzing data, and reporting results. The direction between box 5 and 2 likely suggests that when hypotheses are not supported by experiments, the researcher constructs new hypotheses. Instead of detailed step explanations, the teacher preferred to use these numbers. Perhaps she did not remember these steps.

After the intervention, Teacher Beren created two sets of experiments. In the laboratory set, a person is looking at two beakers on the heaters on the table. Possibly, the sticks in the beakers are thermometers and the person is a scientist. One of the beakers has one heater, while the other has two heaters. The scientist states that he will test hypotheses

regarding the factors affecting boiling with the established setup. In the second setting, a person claims that his new thermometer is functioning because water was boiling at 100 °C. One week later, that person questions why water boiled at a lower degree in the mountains. In her explanation of the post-visualization, the teacher mentioned that there are various ways to produce scientific knowledge. She indicated that she illustrated two approaches to knowledge production. According to her explanation, in the top image, a scientist draws a conclusion in an environment where hypotheses are generated and variables are defined, while in the bottom image, a person arrives at a conclusion based on his daily life experiences. Her post-visualization reflected that she learned there are multiple scientific methods, which can be classified as manipulative and non-manipulative in science. In the above visual, manipulation involved hypothesis testing, while in the below one, exploratory methods were employed without hypothesis testing. It can be concluded that her understanding of scientific methods evolved after the intervention.

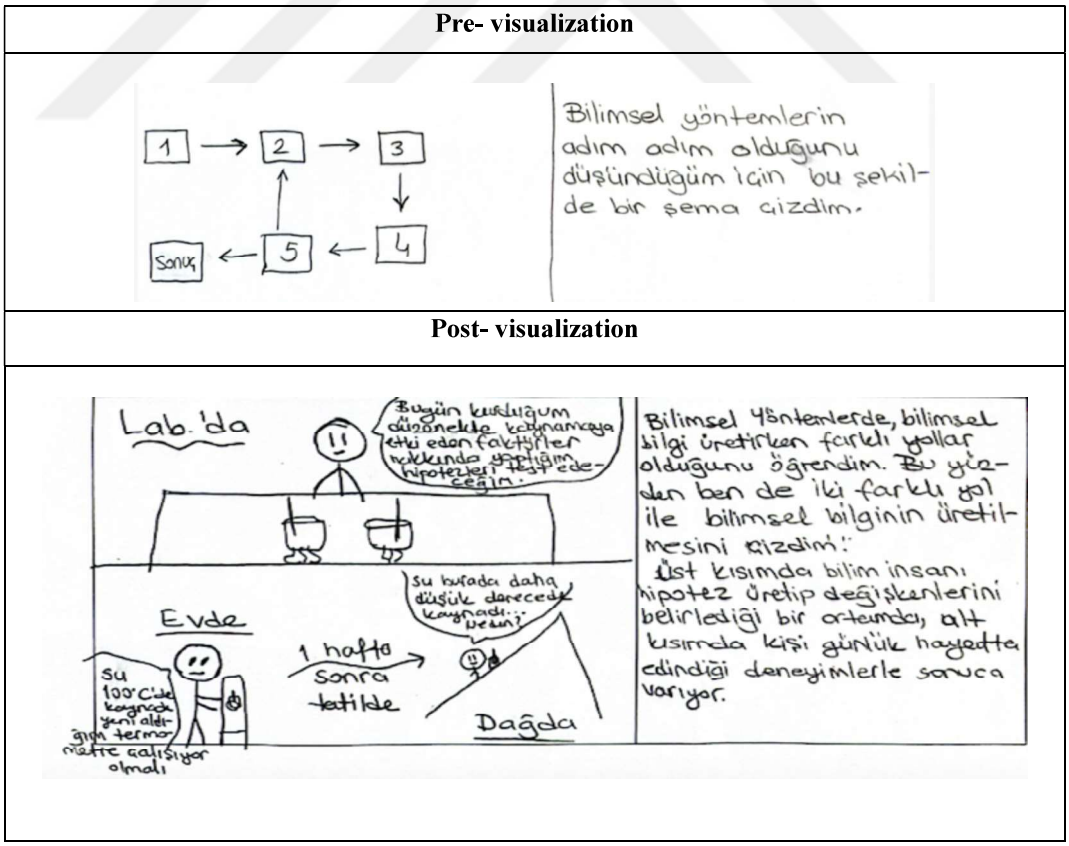


Figure 4.8. Beren's Pre- and Post- Visualizations of the M of RFN.

Beren's Visual Representation of the Scientific Knowledge

In the pre-visualization, Teacher Beren drew a waterfall, trees, and grass. In the explanation part, she emphasized that scientific knowledge changes, develops, and constantly increases. She stated that she deliberately used water as a metaphor. Since water is fluid and mobile, scientific knowledge can change and develop. Teacher Beren's drawing can be interpreted as emphasizing the tentative nature of scientific knowledge.

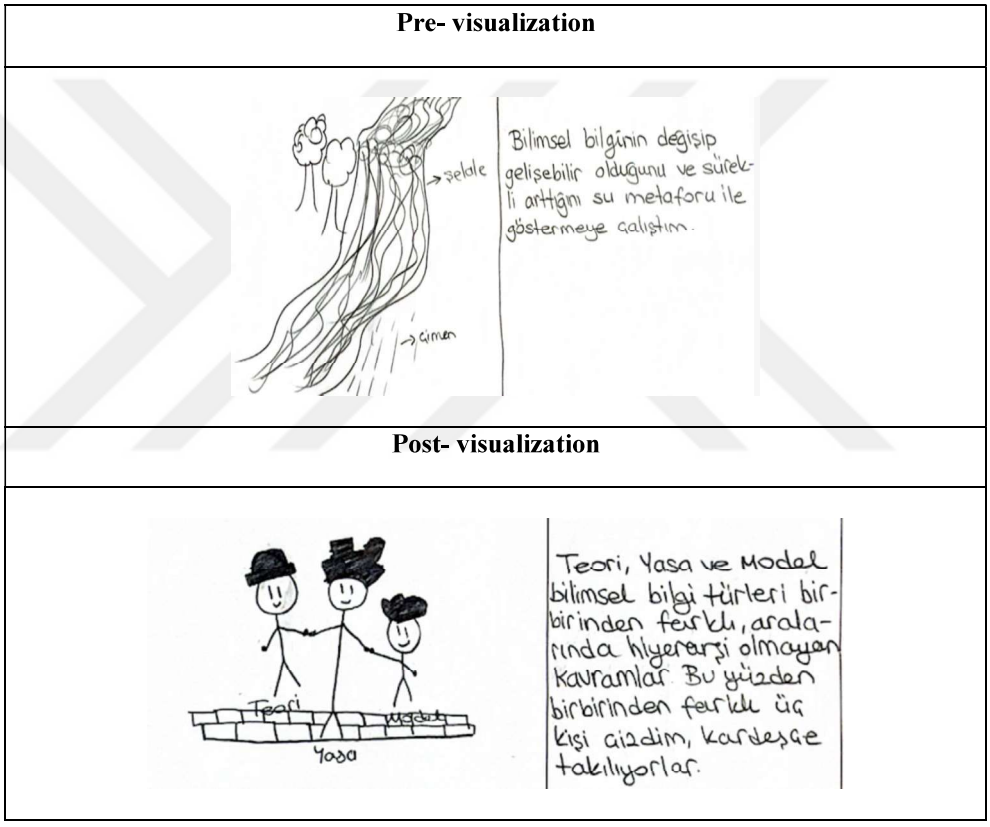


Figure 4.9. Beren's Pre- and Post- Visualizations of the SK of RFN.

After the intervention, Teacher Beren drew a small wall made of bricks. Above the wall, there are three human figures of different heights and wearing different hats. "Theory, model, and law" were written beneath the human figures. The tallest figure is labeled as law, while the smallest is labeled as model. The three figures are holding hands and smiling. She explained her post-visualization by stating that theory, law, and model are various types of scientific knowledge, and there is no hierarchy among them. She also suggested that these types of scientific knowledge interact like brothers. Although the teacher stated there is no

hierarchy, it appears contradictory that the law is depicted as the big brother and the model as the little brother in the visualization. On another note, it can be concluded that the teacher enhanced her understanding of scientific knowledge by focusing on the different types of scientific knowledge.

Beren's Visual Representation of the Social-Institutional Aspects of Science

In the pre-visualization, Teacher Beren illustrated a picture of the Earth showcasing various continents. In her drawing, human figures represented each continent, with arrows indicating that water boils at 100 °C. In her explanation of the visualization, the teacher stated that under different conditions, science will reach the same conclusion. Teacher Beren refers to the objective characteristics of science. The human figures in the drawing represent scientists living in various regions of the Earth.

Pre- visualization



Post- visualization



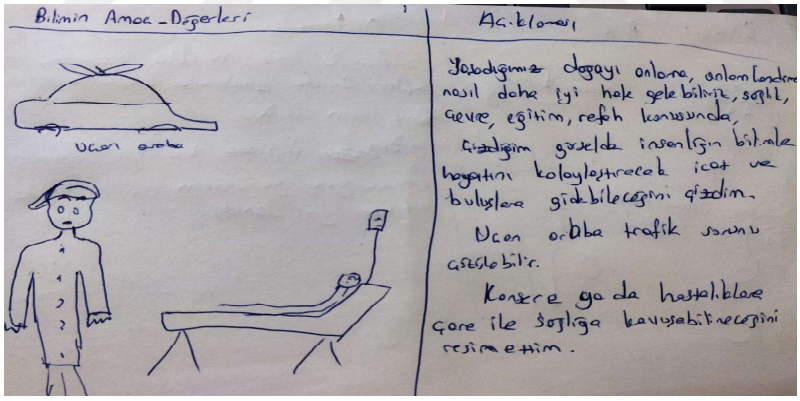
Figure 4.10. Beren's Pre- and Post- Visualizations of the SI of RFN.

4.1.1.3. Case 3 - Deniz's NOS Visualization. Teacher Deniz was unfamiliar with the RFN framework from her pre-service teacher education. However, after participating in the PD program, she demonstrated an improved understanding in her post-visualization.

Deniz's Visual Representation of the Aims and Values of Science

Before the intervention, Teacher Deniz drew a flying car, a doctor, and a patient receiving serum. She perceived the aims and values of science mainly as serving humanity and solving problems according to her drawings. In her pre-explanations, she wrote, "understanding nature, serving humanity, and solving problems" as fundamental aims and values in science, suggesting that a flying car can solve the traffic problem and that advancements in science can help overcome certain diseases. She also noted that improvements in health, education, and the environment increase the welfare of a country.

Pre- visualization



Post- visualization

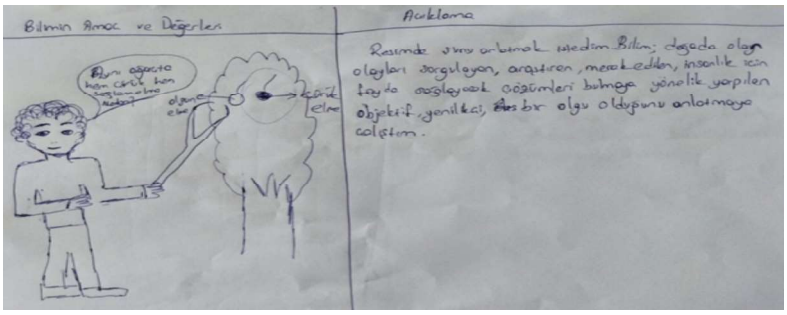


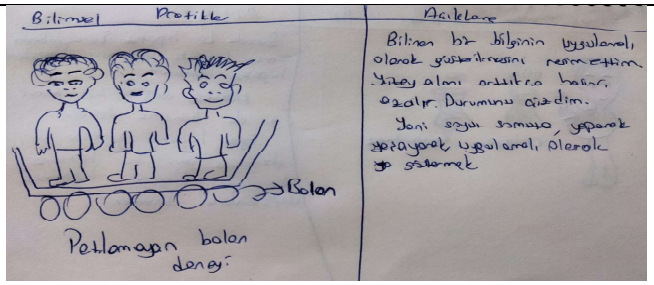
Figure 4.11. Deniz's Pre- and Post-Visualizations of the AV of RFN.

After the intervention, Teacher Deniz drew a man observing the apples on the tree. The man is contemplating how both good and rotten apples can be. He is holding a grabber to reach the branch of the tree. In her pre-explanation, she stated that science is an objective and innovative phenomenon that investigates, questions, and displays curiosity about events in nature, aiming to find solutions that benefit humanity. She referenced some key concepts such as objectivity, novelty, addressing human needs, and critical examination. It can be said that after the intervention, she demonstrated a more sophisticated understanding of the aims and values of science.

Deniz's Visual Representation of the Scientific Practices

Before the intervention, Teacher Deniz drew three kids on a platform above the balloons. She illustrated an experiment regarding the factors (surface area, force) that affect pressure. She viewed scientific practices as modeling, making abstract concepts concrete, and conducting experiments. She created an experimental setup to explore the issue of pressure in science.

Pre- visualization



Post- visualization

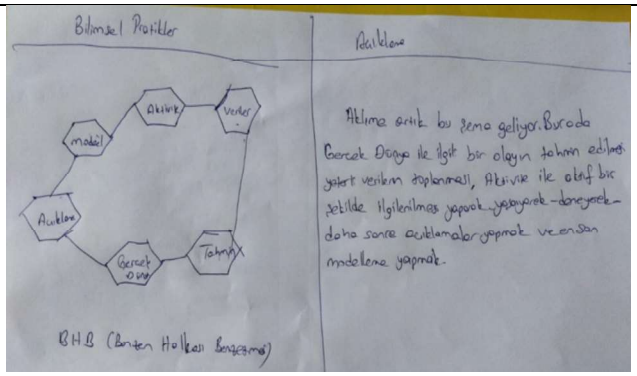


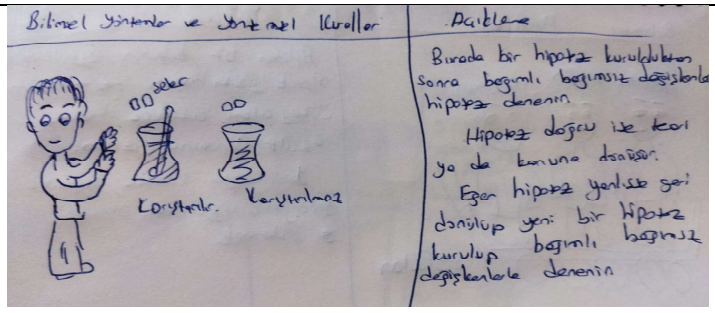
Figure 4.12. Aylin's Pre- and Post-Visualizations of the SP of RFN.

After the intervention, Teacher Deniz drew the Benzene Ring Heuristics (BRH) with epistemic-cognitive components, excluding social components. She wrote the components of "modelling, explanation, data, prediction, real world, and activities." She described these practices as they should be performed in order. In comparing pre- and post-visualization, her perception evolved, and she began to consider many diverse practices.

Deniz's Visual Representation of the Scientific Methods and Methodological Rules

Before the intervention, Deniz drew a human (scientist) and an experimental setup related to the issue of the rate of dissolution in science. In the experimental setup, she drew two glasses, added two sugars to each of them, and only mixed one of them. In her experiment, she aimed to determine the effect of stirring on the dissolution rate. In her pre-explanation, she described scientific methods as a step-by-step process (the lock-step method). She first formed a hypothesis and identified variables, then tested her hypothesis through experiments. If the experiments do not support her hypotheses, she can reconstruct her hypothesis. It was also found that she had misconceptions about theories and laws, believing that theories transform into laws after enough experiments are conducted.

Pre- visualization



Post- visualization

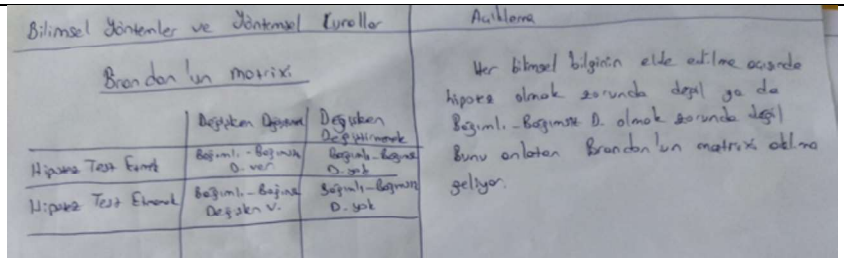


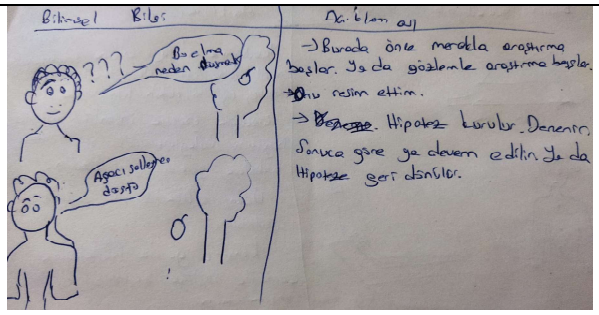
Figure 4.13. Deniz's Pre- and Post- Visualizations of the M of RFN.

After the intervention, she illustrated Brandon's matrix to showcase the diversity of scientific methods. She explained that manipulation and hypothesis testing are not necessary for every scientific study. She did not elaborate on diverse scientific methods in detail but provided examples. On the other hand, it can be said that Teacher Deniz's perception changed considerably.

Deniz's Visual Representation of Scientific Knowledge

Teacher Deniz, in her pre-visualization, depicted two men (scientists) standing next to two trees. One of them ponders, "How is the apple on the tree?" while the other thinks, "When the tree is shaken, the apple falls." She aimed to convey that scientists can hold diverse hypotheses about a natural phenomenon. In her pre-explanation, she noted that scientific knowledge evolves through curiosity, and hypotheses can change or develop into laws after testing. If a hypothesis cannot be tested, it can be reconstructed. This indicated that she viewed scientific methods as a step-by-step process (the lock-step method) and held misconceptions about the functions of laws and theories prior to the intervention.

Pre- visualization



Post- visualization

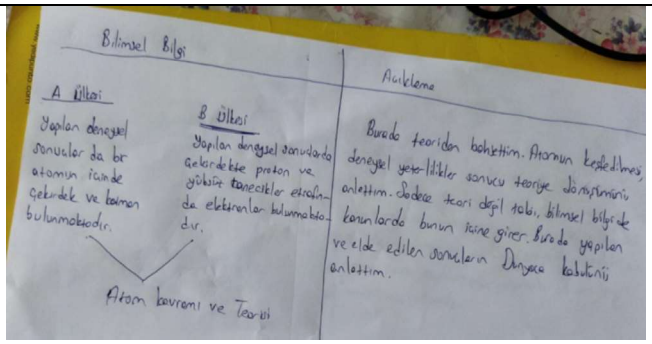


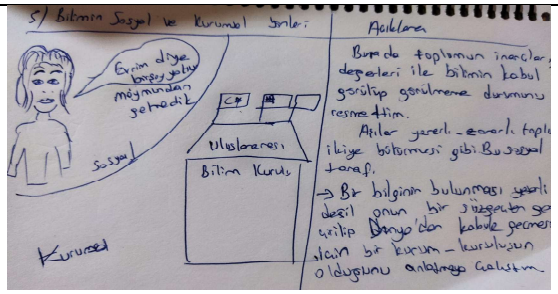
Figure 4.14. Deniz's Pre- and Post-Visualizations of the SK of RFN.

In her post-visualization, she provided examples of two countries contributing to the development of atomic theory. In country A, the core and layer structure of an atom was explored, while in country B, protons and neutrons were examined in the atom's core. She explained that after enough experimentation, a concept can be accepted as a theory or law worldwide. She focused on the development of scientific knowledge. However, she may still have the misconception that one type of scientific knowledge transforms into another. It can be interpreted that teacher Deniz needs to develop her understanding of scientific knowledge.

Deniz's Visual Representation of the Social-Institutional Aspects of Science

In her pre-visualization, Teacher Deniz drew a human who has opposing ideas about science, such as "evolution is not true" and "humans did not descend from monkeys." In her explanation, she wrote that she wanted to emphasize the impact of cultural beliefs and values on science as a social aspect of it. She provided examples of diverse ideas about vaccines in her explanation. She illustrated an institution representing an international science board adorned with diverse flags. According to her, there are certain institutions involved in the certification process of SK, which represent the institutional aspects of science.

Pre- visualization



Post- visualization

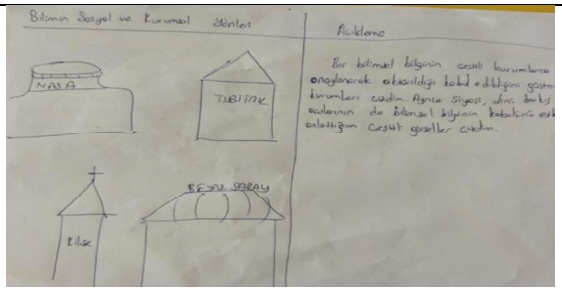


Figure 4.15. Deniz's Pre- and Post- Visualizations of the SI of RFN.

In her post-visualization, she portrayed scientific institutions like NASA and TUBİTAK, along with various religious and political entities such as the church and the White House, to demonstrate how science has influenced them. In her post-explanation, she indicated that the certification of scientific knowledge can occur in certain scientific institutions, while political and religious factors have impacted the advancement of scientific knowledge. When comparing pre- and post-visualizations, she recognizes some components of the SI aspects of science, but she needs to develop her understanding further. No change was observed between her pre- and post-visualizations.

4.1.1.4. Case 4 – Leyla's NOS Visualization. Teacher Leyla was familiar with the RFN framework from her pre-service teacher education. Thus, her prior understanding of each category was solid. On the other hand, through the PD program, she found opportunities to discuss and learn the sub-components of each category. It was noted that after the intervention, her sophisticated understanding developed, and she provided more examples and thought more holistically.

Leyla's Visual Representation of the Aims and Values of Science

Teacher Leyla had a good level of perception about the aims and values of science before the intervention. She drew a jigsaw puzzle illustrating diverse dimensions such as cognitivism, epistemology, politics, ethics, and sociality as components of the puzzle. She used an analogy and explained that the aim of science is to complete the puzzle and construct the picture. This means that all these aspects play a role in science, and the jigsaw represented how science should encompass all of them. However, in her pre-explanation, she did not provide specific examples of these issues.

After the intervention, she drew a daisy, with its two leaves representing the epistemic cognitive and social aims and values. She explained that the petals of the daisy represent all aims and values, such as "objectivity, honesty, empirical adequacy, serving to humanity, critical examination, and addressing anomalies and counter instances." According to her, the flower symbolizes a scientific study, and depending on the study, the number of petals can change. It can be said that the teacher's level of sophisticated understanding

developed after the PD program. She appeared to be aware of the epistemic-cognitive and social aims and values of science.

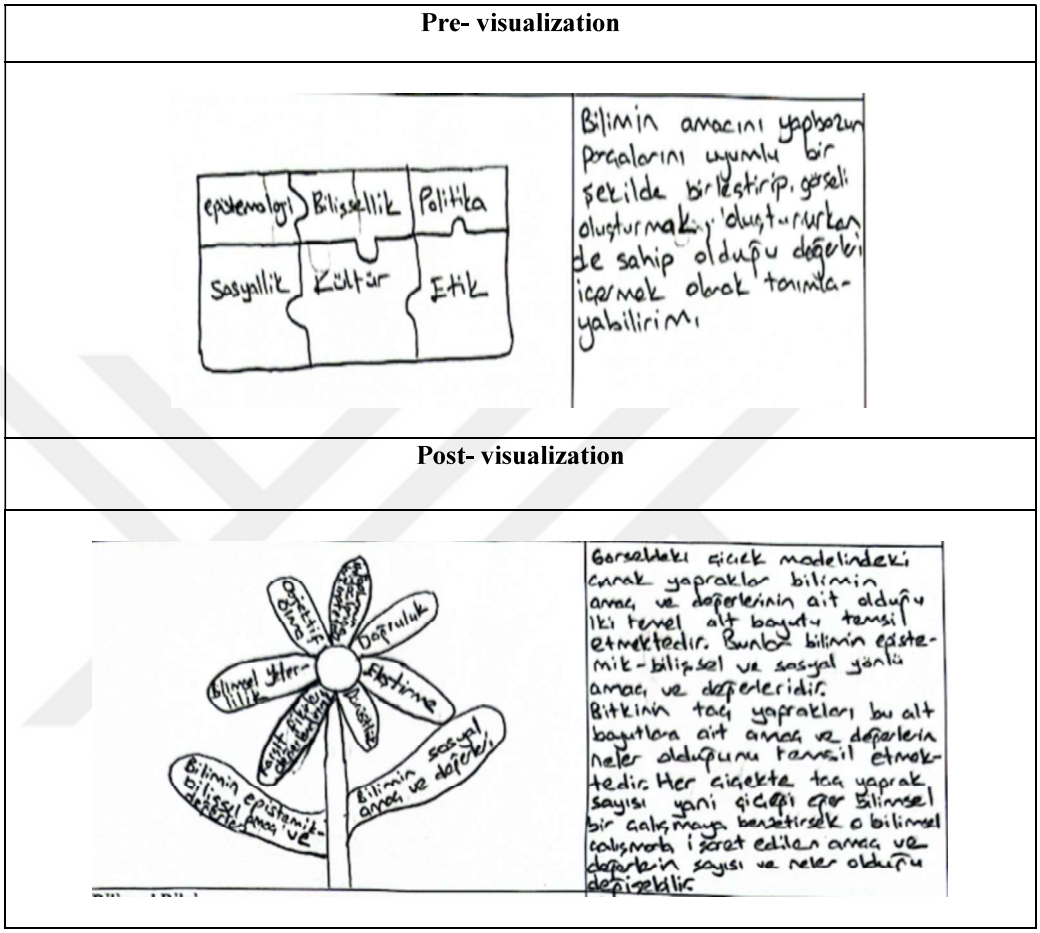


Figure 4.16. Leyla's Pre- and Post- Visualizations of the AV of RFN.

Leyla's Visual Representation of the Scientific Practices

Before the intervention, Teacher Leyla drew a graph to represent gathering data, illustrated by a human with a magnifying glass to depict making observations, a group of people to signify engaging in discussions, two beakers to denote conducting experiments, a person with a thought cloud to represent making predictions, and two cars on differently structured roads to symbolize hypothesis testing. Finally, she included the sun, earth, and moon to represent modeling. In her pre-explanation, she emphasized that diverse scientific practices can be applied across various disciplines. She viewed scientific practices as

scientific methods and had a good understanding of them. However, she did not view scientific practices holistically prior to the intervention.

Pre- visualization



Post- visualization

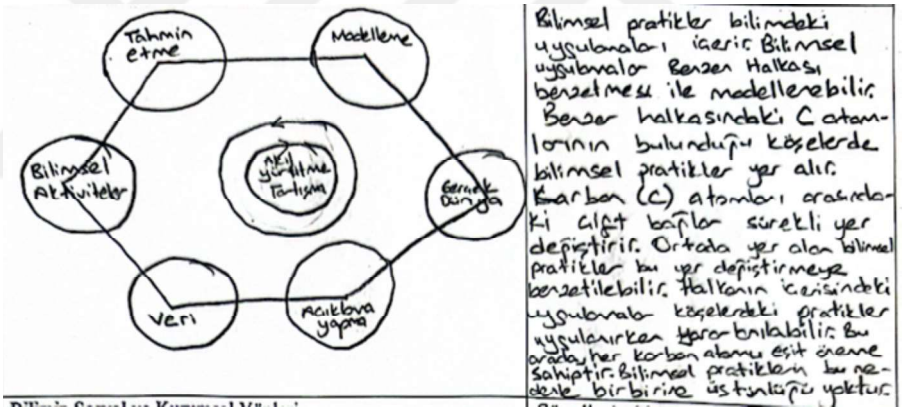


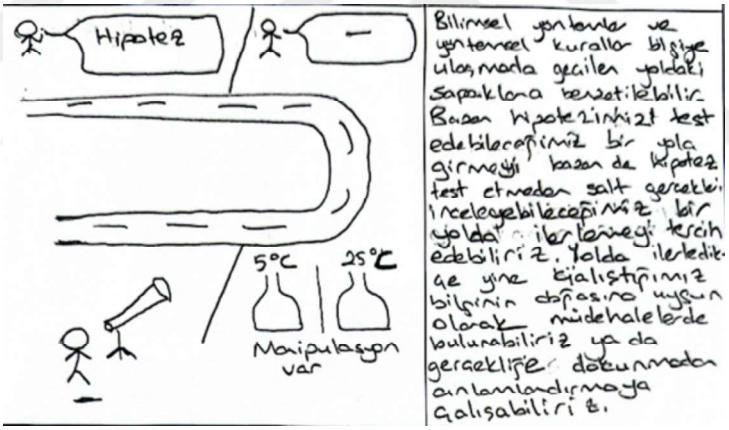
Figure 4.17. Leyla's Pre- and Post- Visualizations of the SP of RFN.

After the intervention, she drew Benzene Ring Heuristics (BRH) developed by Erduran and Dagher (2014). She wrote each practice in the circles and connected the circles to form a hexagon. These practices are "prediction, modelling, real world, explanation, scientific activities, and data." She also drew two directional circles inside the hexagon and wrote "reasoning, discussion" as social practices in them. Teacher Leyla explained the analogy behind the theoretical background of BRH very well. She emphasized that there is no hierarchical order among the scientific practices and that social practices within the BRH can be used alongside other practices. It can be said that after the PD, she began to think about scientific practices holistically.

Leyla's Visual Representation of the Scientific Methods and Methodological Rules

Before the intervention, Teacher Leyla depicted scientific methods as a winding road that could include hypothesis testing, manipulation, or observational methods. She drew two men, one of whom had a hypothesis and the other did not. She also illustrated an experimental setup with two beakers at different temperatures to represent manipulation, and a telescope to represent observational methods. She explained that depending on the nature of the study, there can be manipulation or, alternatively, sense-making through observation. She focused on the diversity and domain specificity of scientific methods. She had a good understanding of scientific methods before participating in the PD program, but she needed to better explain the interaction between hypothesis testing and manipulation.

Pre- visualization



Post- visualization

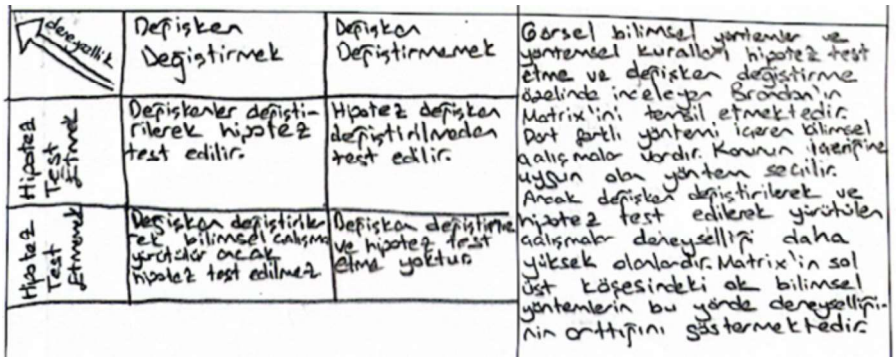


Figure 4.18. Leyla's Pre- and Post- Visualizations of the M of RFN.

After the intervention, she visualized Brandon's matrix. She explained four approaches to scientific methods: (1) manipulation with hypothesis testing, (2) manipulation without hypothesis testing, (3) non-manipulation with hypothesis testing, and (4) non-manipulation without hypothesis testing. She noted that if a study involves both manipulation and hypothesis testing, it is more experimental in nature. It seems that after the intervention, her understanding of scientific methods developed, and she explained the interaction between manipulation and hypothesis testing more clearly.

Leyla's Visual Representation of the Scientific Knowledge

Before the intervention, teacher Leyla listed two characteristics of scientific knowledge. First, she noted that one misconception is that "hypotheses transform theories, theories transform laws." To illustrate this misconception, she wrote the concepts of hypothesis, theories, and laws, then drew a directional arrow among them and crossed out this diagram. Secondly, she drew a rectangle and labeled its four corners with hypothesis, theory, model, and scientific understanding. She explained that there is no hierarchy among hypotheses, theories, and laws. Additionally, she used the analogy of scientific knowledge as a cloth that can be shaped by corners with all these forms of knowledge that provide scientific understanding. It can be said that the teacher had pre-knowledge about the nature of scientific knowledge types and some common misconceptions about them.

After the intervention, Teacher Leyla drew a cone in which each layer consists of theories, laws, and models (TLM). She also drew a disk belonging to this cone. As knowledge grows, the cone expands. She explained that there is no hierarchical order among the diverse types of scientific knowledge, and they provide scientific understanding collectively. During the intervention, teachers were shown visuals of the TLM table and TLM wall to illustrate how scientific knowledge expands with the addition of new scientific ideas. It can be said that Teacher Leyla's perception has developed, and she has begun to think more holistically and sophisticatedly. She showed the growth of the scientific knowledge different from the example visuals showed them in the PD program.

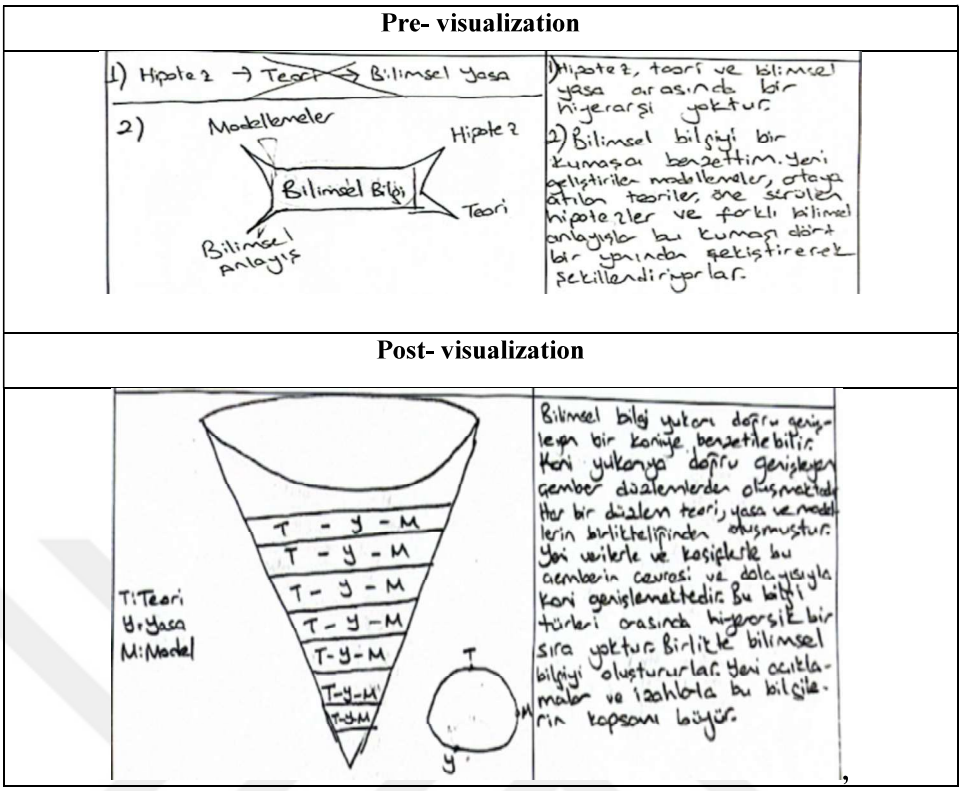


Figure 4.19. Leyla's Pre- and Post- Visualizations of the SK of RFN.

Leyla's Visual Representation of the Social-Institutional Aspects of Science

At the beginning of the study, teacher Leyla perceived social-institutional aspects of science as factors that affect the knowledge generation process. Thus, she labeled the product box as science. She drew a machine to represent the process of scientific knowledge development, writing the concepts of "ethics, political values, financial issues, social relations, social values, and social organizations" as the inputs of the machine. This means these factors influence how this machine operates and, consequently, how science functions. In other words, all these factors impact the product, represented as science. Teacher Leyla had a strong understanding before participating in the PD program.

After the intervention, she drew concentric circles to indicate all social-institutional aspects of science. In the inner circle, scientific knowledge is placed, with all other social-institutional aspects encompassing scientific knowledge. There is an interaction between scientific knowledge and the social-institutional aspects of science. These aspects include "universality as scientific values"; "serving humanity as social values"; "the effect of

governments as political factors"; "examining other studies and writing conference proposals as professional activities"; "sharing scientific knowledge with others as social certification and dissemination"; "the effect of economy on science as financial factors"; and finally, "integrations among the scientific institutions as social organization and interactions." It was observed that after the intervention, her sophisticated understanding and examples of social-institutional aspects of science developed.

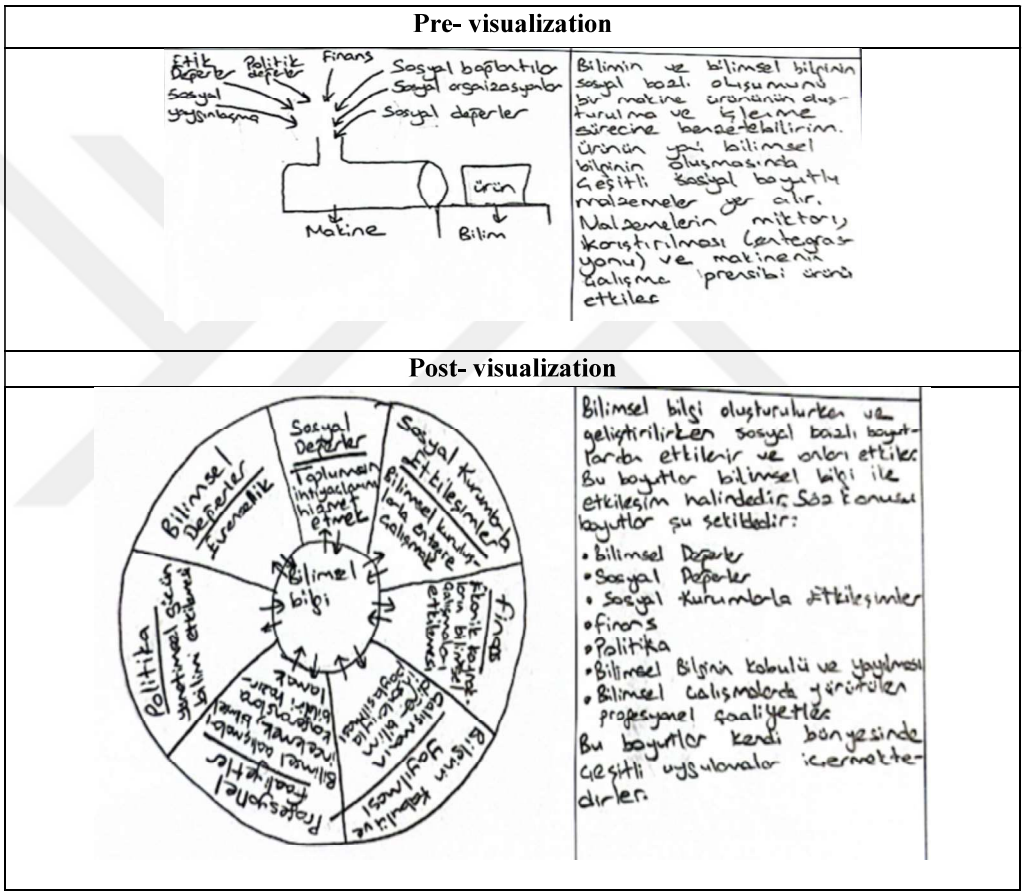


Figure 4.20. Leyla's Pre- and Post- Visualizations of the SI of RFN.

4.1.1.5. Case 5 – Melisa's NOS Visualization. Teacher Melisa was familiar with the RFN framework from her pre-service teacher education. Thus, her initial perception of each category was good. However, through the PD program, she found opportunities to discuss and learn the sub-components of each category. It was observed that after the intervention, her sophisticated understanding developed; she provided more examples and thought more holistically.

Melisa's Visual Representation of the Aims and Values of Science

Before the intervention, Teacher Melisa illustrated a falling object in a tree (physics), two planets (astronomy), and an excavation site (anthropology) to represent the aims and values of science. She concentrated on examples from the various branches of science. She explained that the aims and values of science are to "understand nature," "make unbiased explanations," and "ensure objectivity and validity."

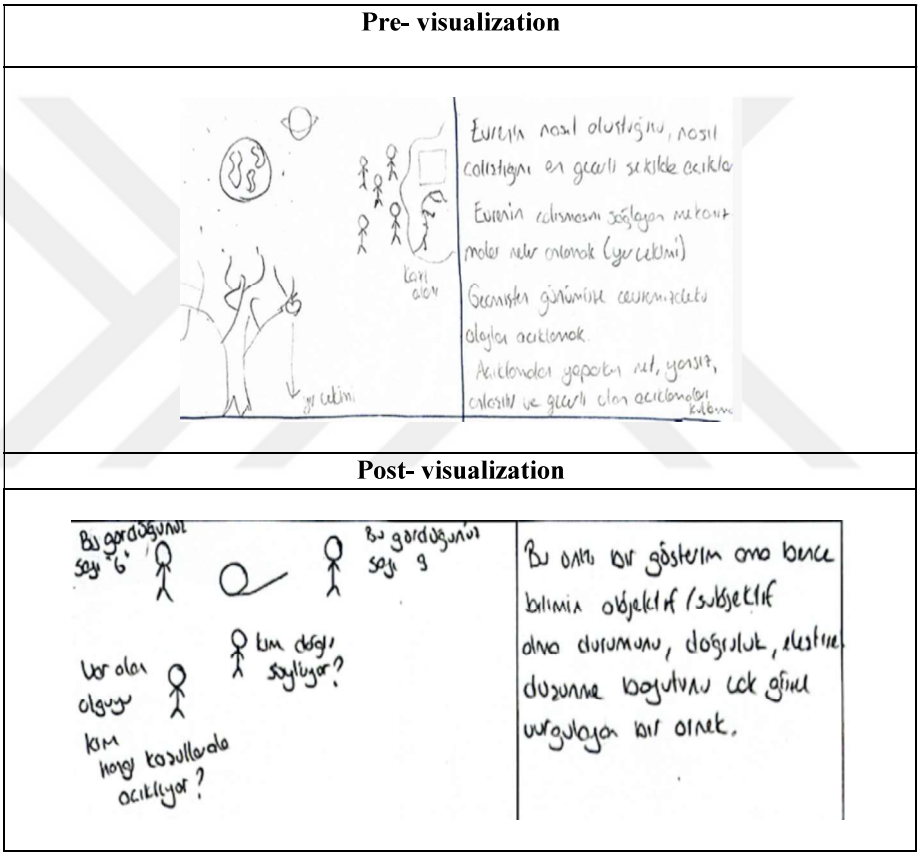


Figure 4.21. Melisa's Pre- and Post- Visualizations of the AV of RFN.

After the intervention, she gathered people with opposing views on a phenomenon. For example, one of them says, "It is 6," while another says, "It is 9," and the other men ask, "Who says true? Who explains the existing phenomenon and under what conditions?" She elaborated in her post-visualization by stating that science should encompass concepts such as objectivity, subjectivity, accuracy, and critical examination. It can be said that Melisa focused on diverse analytical viewpoints in her pre- and post-visualizations. This may be

related to the text they read during the analytical viewpoint workshop, where Teacher Melisa emphasized issues of objectivity, accuracy, and critical examination within her group.

Melisa's Visual Representation of Scientific Practices

Teacher Melisa illustrated an experimental setup to represent experimentation. In her setup, she drew two potted plants: one in the sun and the other in the shade. She also included a telescope and celestial bodies to symbolize observation in scientific practices. She explained her pre-visualization, noting that changing variables, making observations, and drawing inferences are fundamental scientific practices. It was noted that before the intervention, Teacher Melisa mentioned only two kinds of scientific practices.

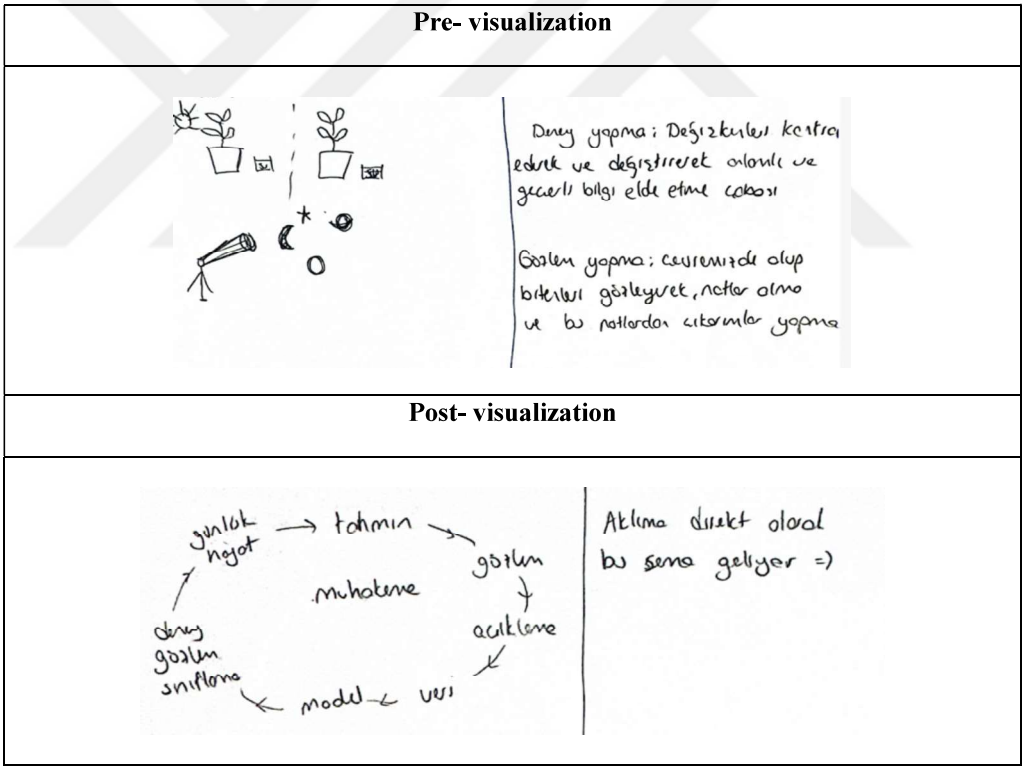


Figure 4.22. Melisa's Pre- and Post- Visualizations of the SP of RFN.

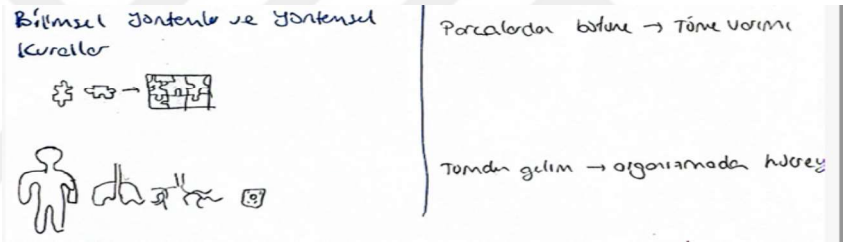
After the intervention, she drew Benzene Ring Heuristics (BRH) with components from real life: prediction, observation, explanation, modeling, experimentation, observation, classification, and reasoning. She drew a one-directional arrow among them and wrote reasoning in the center of the circle. It can be said that after the intervention, her perception

of scientific practices developed, as she listed more scientific practices. She was influenced by the PD program, and thus she drew BRH after the intervention.

Melisa's Visual Representation of Scientific Methods and Methodological Rules

Before the intervention, Teacher Melisa created a jigsaw puzzle to represent inductive methods and used images of a body to illustrate deductive methods (body, system, organs, cell). She viewed scientific methods as methods of scientific reasoning. It can be said that her initial understanding of scientific methods was limited and required further development.

Pre- visualization



Post- visualization

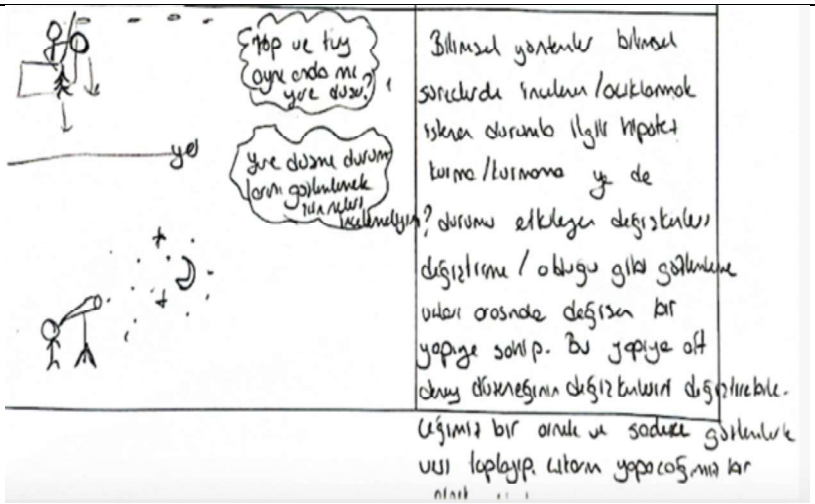


Figure 4.23. Melisa's Pre- and Post- Visualizations of the M of RFN.

After the intervention, she drew a man throwing a ball and a feather and asks the question, "Do the ball and the feather fall to the ground at the same time?" and "What should

I examine to observe falls to the ground?" In another picture, she drew a telescope and celestial bodies. In her post explanation, she expressed that scientific methods have a spectrum, including hypothesis testing or not, manipulation or not, and making observations. Although she did not mention the Brandon matrix by name, she referred to its categories. It can be said that her perception developed after the PD program.

Melisa's Visual Representation of Scientific Knowledge

Before the intervention, Teacher Melisa illustrated two masses exerting force on each other (the law of gravity) and set up an experiment that included two beakers and a lab report form. She also referenced the universe and the Big Bang theory, noting that theories explain how the universe works. Additionally, she highlighted that methodological knowledge, such as reports and observation notes, demonstrates how science is conducted. It can be said that at the beginning of the study, she had knowledge of different types of scientific knowledge, specifically theories and laws. However, she did not clarify their functions and relationships.

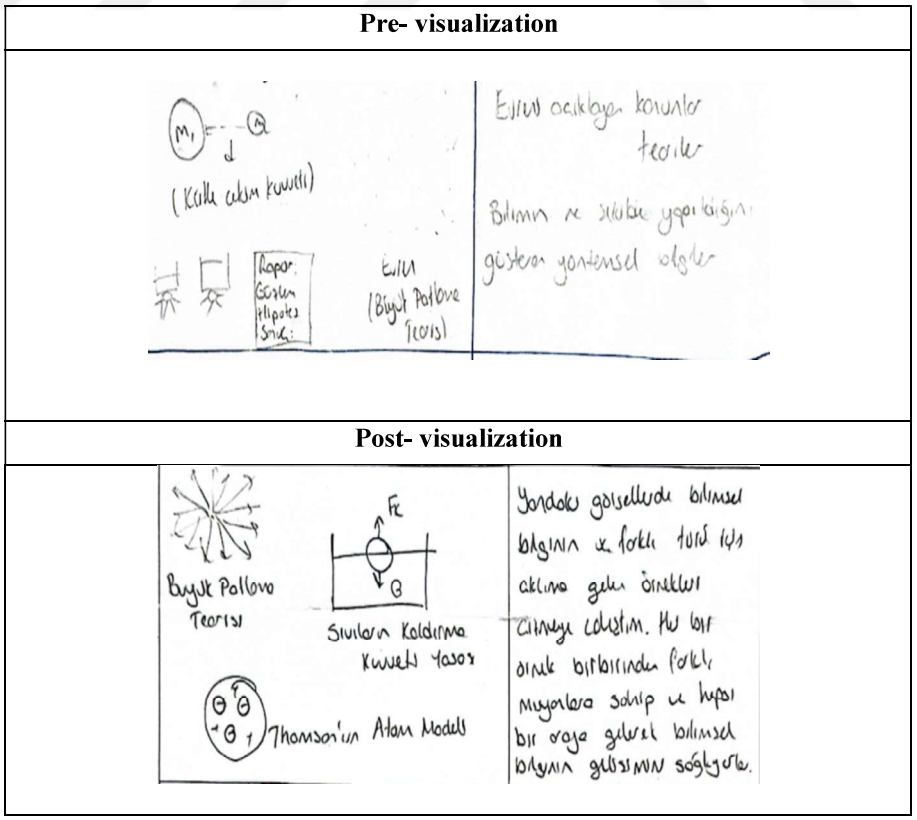


Figure 4.24. Melisa's Pre- and Post- Visualizations of the SK of RFN.

After the intervention, she created an explosion model to illustrate the Big Bang theory; a beaker with mass and forces exerted on it to represent the law of buoyancy, and a circle containing positive and negative charges to depict Thomson's atom model. These examples refer to TLM (theories, laws, and models). According to Teacher Melisa, different types of scientific knowledge serve diverse functions, and when they come together, they contribute to the development of scientific knowledge.

Melisa's Visual Representation of the Social- Institutional Aspects of Science

Before the intervention, Teacher Melisa focused on key aspects of the social-institutional dimensions of science. She illustrated a presenter in front of the board conducting a presentation at a conference to represent professional activities; articles and journals to depict social certification and dissemination of scientific knowledge; a group of people around a table meeting for budgeting to signify the political and financial facets of science; and vaccines and planes to illustrate the needs of society. According to her pre-explanation, scientists participate in conferences and share their studies with other scientists through journals, while also addressing the needs of society. They require financial support to conduct their research; therefore, some institutions came together. It can be said that she had a good level of understanding of SI before participating in the PD program.

After the intervention, she illustrated a presenter in front of the board during a conference to represent professional activities; articles and journals to represent social certification and dissemination of scientific knowledge; a group of people on an online platform, a university, and TÜBİTAK to represent social organizations; and a TV program featuring discussions by scientists about the effects of artificial intelligence on daily life to dissemination of scientific knowledge. She explained all visuals in her explanation part. It can be said that teacher Melisa has a good understanding before and after the intervention, as she referred to many sub-categories of social-institutional systems of science. Her post-intervention visualization demonstrated a more nuanced perspective, integrating both formal and informal mechanisms of science communication. This indicates an expanded awareness of the diverse ways in which science interacts with society beyond the laboratory.

Pre- visualization



Post- visualization

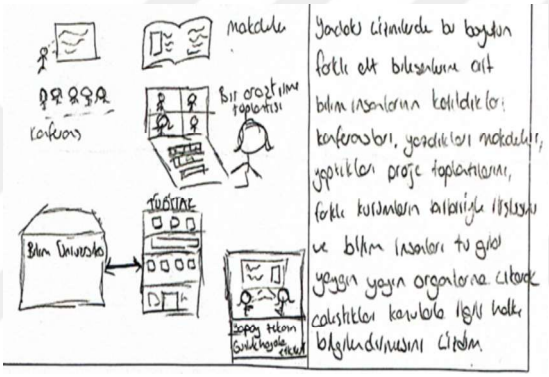


Figure 4.25. Melisa's Pre- and Post- Visualizations of the SI of RFN.

4.1.1.6. Case 6 - Zeynep's NOS Visualization. Teacher Zeynep was unfamiliar with the RFN framework from her pre-service teacher education. She demonstrated a developed understanding in her post-visualization.

Zeynep's Visual Representation of the Aims and Values of Science

Before the intervention, Teacher Zeynep drew a scientist making observations with a microscope, notebook, test tube, and beaker. She explained the aims and values of science as the exploration of scientific knowledge through experiments. In her pre-explanation, she noted that aims and values of science is conducting studies for exploration of SK. It can be said that prior to the intervention, she had a limited understanding of the aims and values of science.

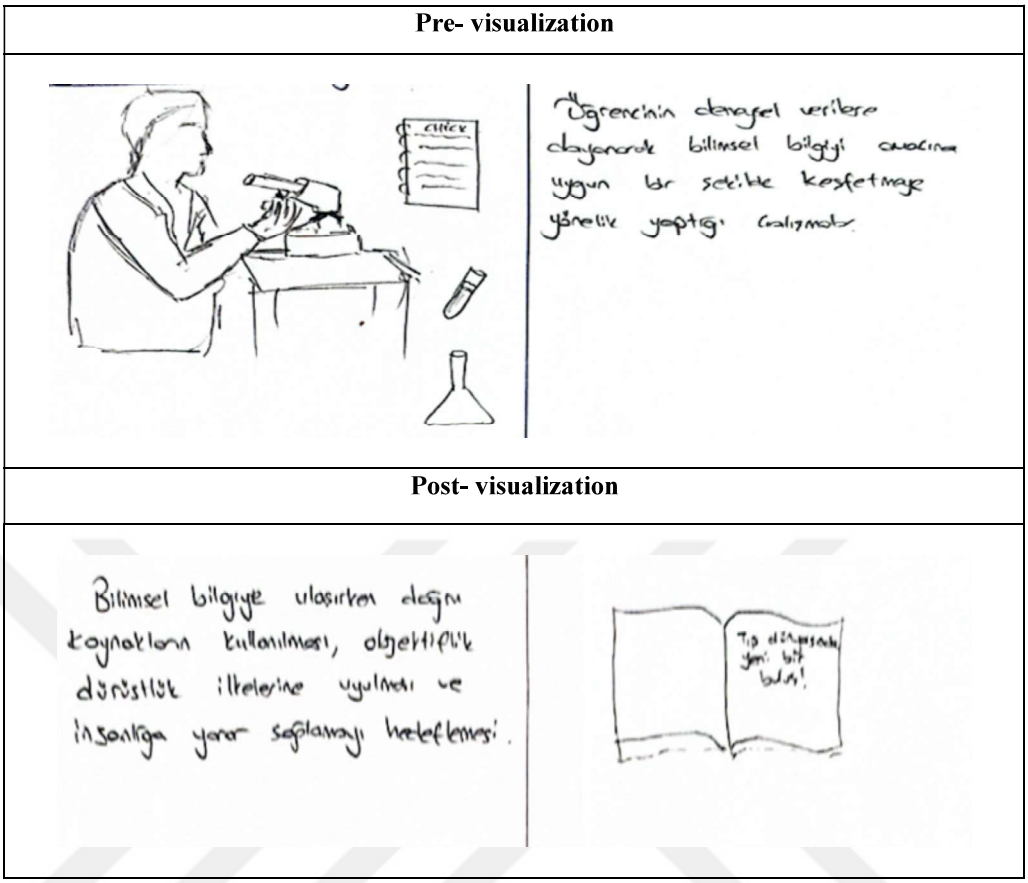


Figure 4.26. Zeynep's Pre- and Post- Visualizations of the AV of RFN.

After the intervention, she drew a book and wrote on it, "A new discovery in the medical world!" It seemed that she perceived the aims and values of science as discoveries that serve humanity. In her post-visualization, she explained that the issues of "accuracy, objectivity, honesty, and serving humanity" are the aims and values of science. It can be said that her perception developed.

Zeynep's Visual Representation of the Scientific Practices

In her pre-visualization, Teacher Zeynep drew laboratory materials such as white coats, glasses, pencils, petri dishes, notebooks, etc. She described her visualization as the process of conducting experiments, making observations, and investigating to test knowledge. It can be said that before the intervention, she could not distinguish scientific practices from scientific methods and had a limited perception of scientific practices.

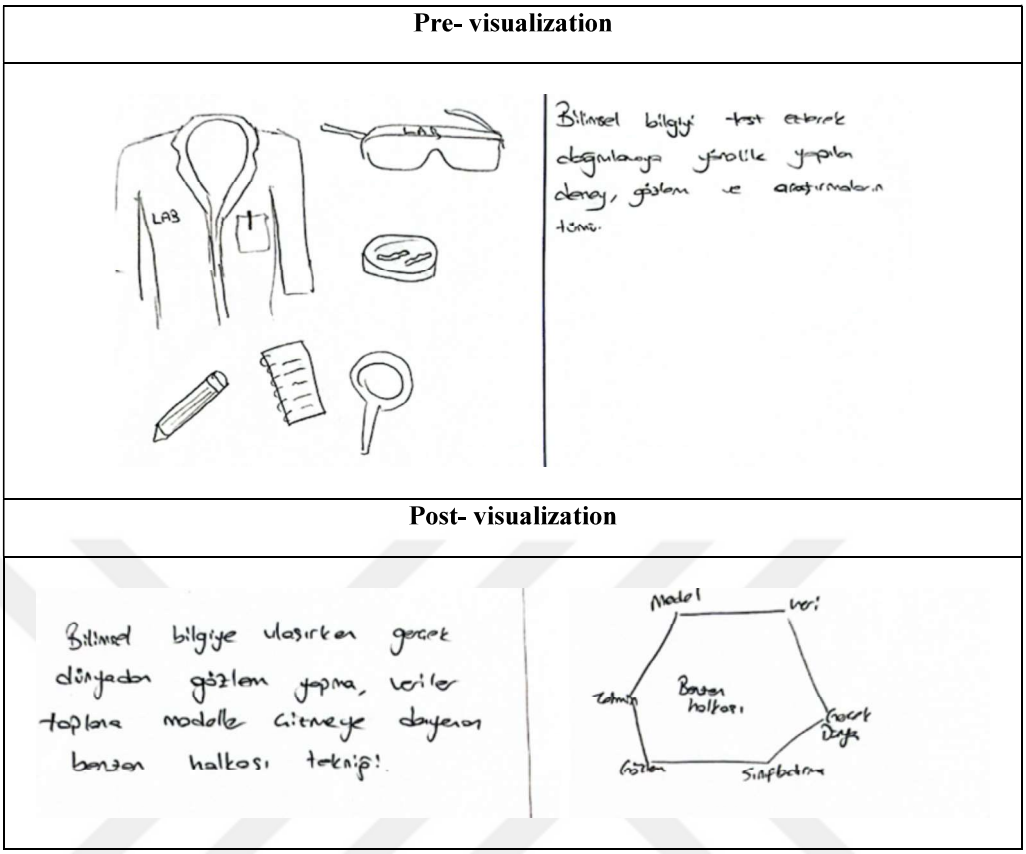


Figure 4.27. Zeynep's Pre- and Post- Visualizations of the SP of RFN.

After the intervention, she drew Benzene Ring Heuristics (BRH) developed by Erduran and Dagher (2014) with the components "modelling, data, prediction, observation, classification, and real world." It was noted that she did not mention social scientific practices such as discussions, discourse, reasoning, and representation. This indicates that her perception of scientific practices developed after the intervention.

Zeynep's Visual Representation of the Scientific Methods and Methodological Rules

Before the intervention, Teacher Zeynep drew a lab animal (a rat), lab materials (a magnifying glass, a funnel), and a warning sign for ethical issues. She explained scientific methods as data collection and experimentation. She also emphasized ethics in scientific studies when selecting a scientific method. Before participating in the PD program, she had a limited perception of scientific methods.

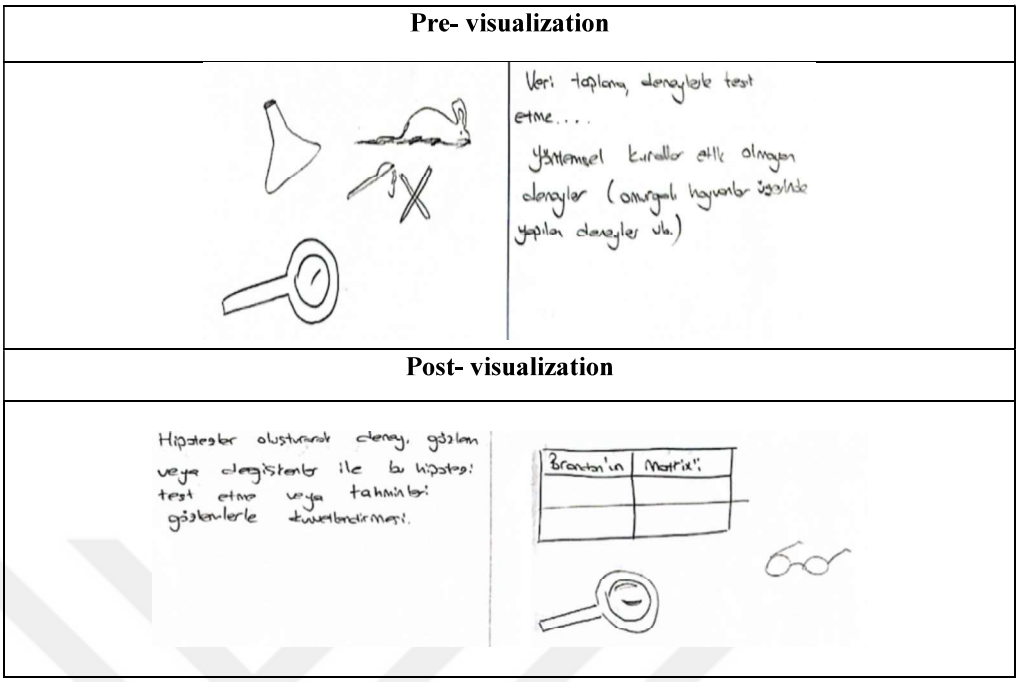


Figure 4.28. Zeynep's Pre- and Post- Visualizations of the M of RFN.

After the intervention, she drew Brandon matrix, glasses, and a magnifying glass. However, she did not fill in the blanks on the table. She explained her visualization by stating that scientific methods can include hypothesis testing or not, manipulation (changing variables) or not, and observation or not. It can be said that after the intervention, her perception of scientific methods developed, and she began to mention various scientific methods. However, she did not internalize scientific methods and struggled to articulate the different types of scientific methods.

Zeynep's Visual Representation of Scientific Knowledge

Before the intervention, teacher Zeynep drew a ruler, a book, and a question mark to represent scientific knowledge. In her pre-explanation, she stated that the nature of scientific knowledge is testable, verifiable, and uncertain. She highlighted its tentative nature through the question mark. It can be said that before the intervention, she was aware of the characteristics of scientific knowledge but not the different types of it.

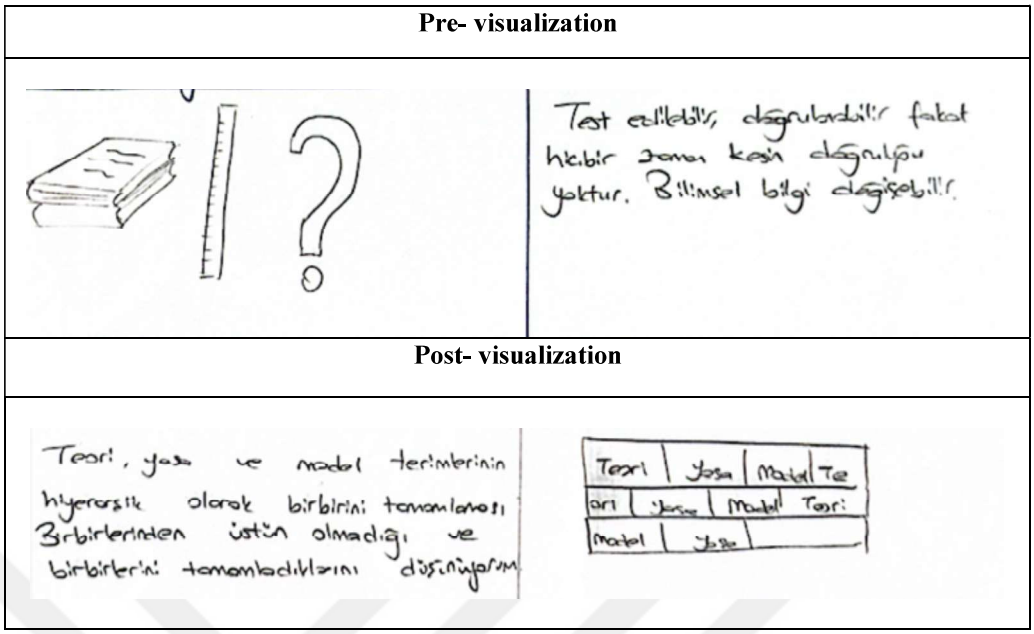


Figure 4.29. Zeynep's Pre- and Post- Visualizations of the SK of RFN.

After the intervention, she created a wall made of stones representing theories, laws, and models (TLM). She explained that there are various kinds of scientific methods, which are not hierarchical; rather, they complement each other. In the PD program, this visual (a wall) served as an alternative teaching tool for conveying scientific knowledge in science lessons. It can be said that teacher Zeynep was influenced by the PD program. Her use of the wall metaphor suggests a shift toward a more integrated and constructivist view of scientific knowledge, emphasizing the interdependence of its components.

Zeynep's Visual Representation of the Social-Institutional Aspects of Science

Before the intervention, Teacher Zeynep drew emblems of scientific institutions such as NASA, TUBİTAK, and a car that is a national technological project, TOGG. She explained that all national and international scientific projects, like TEKNOFEST, NASA, and TOGG, involve social-institutional aspects of science. In her pre-drawing, she mainly focused on the social organizations and interactions subcategory of RFN. Her representation lacked references to other critical dimensions of SI, indicating a somewhat narrow understanding of how science functions within society. It can be said that her perception of the SI aspects of science was limited before the intervention.

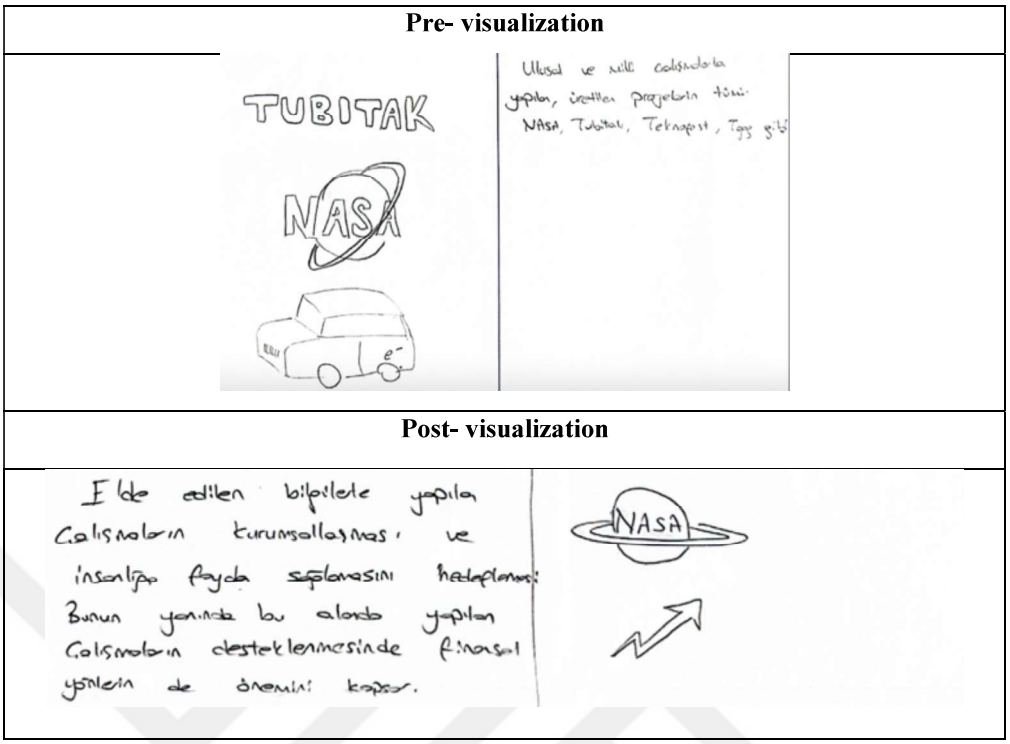


Figure 4.30. Zeynep's Pre- and Post- Visualizations of the SI of RFN.

After the intervention, she drew emblems of NASA. She explained that the certification of scientific knowledge, service to humanity, and financial issues are connected to social and institutional aspects of science. On the other hand, she did not fully convey her perceptions through her drawings. She might have difficulty visualizing her ideas, or her development may have been limited after the intervention. The interview results provide a clearer understanding of her perceptions.

4.1.1.7. Summary of the Visual Representations of the Cases. This section aims to compare and contrast the visual representations for each case. To facilitate the comparison, Table 4.1 summarizes the codes obtained from the visual representations before and after participating in the PD program for each case. In general, it can be said that following the intervention, almost all codes obtained from the visual representations demonstrated development. Teacher Leyla and Melisa had some pre-existing knowledge about the RFN. Thus, their NOS perceptions were better compared to others in their pre- and post-visualizations. After the intervention, it can be said that teachers provided more sophisticated examples in their visualizations. The comparison was made for each RFN category, considering all cases.

Regarding the aims and values of science, Teacher Aylin, Beren, and Deniz focused on social aims and values, such as serving humanity, solving problems, and developing society, as well as honesty. Teacher Leyla and Melisa connected to epistemic cognitive aims and values, which include explanation and objectivity. Teacher Zeynep linked to scientific practices of observation and experimentation. After participating in the PD program, they referred to epistemic-cognitive and social values such as decentralizing power, serving humanity, accuracy, critical examination, objectivity, honesty, empirical adequacy, addressing anomalies, and counterinstances. It can be concluded that teachers' visualization of the aims and values of science improved after the intervention.

It can be said that before the intervention, teachers generally perceived scientific practices as experimentation, observation, discussion, and modeling. Teacher Aylin made connections with scientific knowledge. Only Teacher Leyla connected with almost every component of BRH before the intervention. After the intervention, all teachers developed their perceptions of NOS and referred to BRH in their visualizations.

Teachers generally had a naive understanding of scientific methods before the intervention. Teacher Aylin focused on the specificities of different branches, while Teacher Beren and Deniz referred to a step-by-step method (the lock-step method) in their visualizations. Teacher Melisa described scientific methods as inductive and deductive, while Teacher Zeynep connected these methods with scientific practices such as data collection and experimentation. Only Teacher Leyla mentioned hypothesis testing, manipulation, and observational methods. After the intervention, all teachers referenced Brandon's matrix, which includes four approaches to scientific methods: hypothesis testing, non-hypothesis testing, manipulation, and non-manipulation.

For the scientific knowledge category of RFN, teachers generally introduced various types of scientific knowledge, including theories and laws. Teacher Deniz had misconceptions about scientific knowledge, believing that theories transform into laws when sufficient evidence is presented. Additionally, Teachers Beren and Zeynep emphasized the tentative nature of scientific knowledge. After the intervention, all teachers, except Teacher Deniz, described scientific knowledge using TLM. They highlighted the differences between theories and laws and explained the cumulative development of scientific knowledge.

Before the intervention, teachers generally reflected on the social-institutional aspects of science, including the institutions where science is conducted, the certification of scientific knowledge, cultural and political aspects, as well as professional activities. After the intervention, they focused on scientific values, social values, political factors, professional activities, social certification and dissemination, financial factors, and social organization and interactions. The visualizations of Teachers Deniz and Zeynep are less developed than those of their peers. Teacher Leyla's visualization is the most sophisticated compared to those of the other teachers.

It can be concluded that teachers' NOS visualizations developed after participating in the PD program, regardless of whether they had prior knowledge about RFN. Table 4.1 shows how the diversity of codes increased after the intervention for each case from visual representations. It can be said that teachers were influenced by the examples in the PD program. Specifically, they benefited from the models of Benzene Ring Heuristics, Brandon's matrix, and the TLM wall in their visualizations. The next section presents the findings obtained from individual interviews conducted before and after the PD program.

Table 4.1. Codes obtained from the visual representation for each c

Cases/ Categories	Aylin	Beren	Deniz	Leyla	
AV-Pre	Experimentation Developing society Serving to humanity	Honesty	Serving to humanity Solving the problems Understanding nature	Cognitivism Epistemology Politics Ethics Sociality	
AV-Post	Ethical rules Decentralizing power Serving to humanity Accuracy Critical examination	Honest Critical thinking Universality empirical adequacy Serving to humanity	Objectivity Novelty Addressing human needs Critical examination Serving to humanity Solving problems	Epistemic cognitive, and social values Objectivity Honesty Empirical adequacy Serving to humanity Critical examination Addressing anomalies and counter instances	
SP-Pre	Scientific knowledge (facts, laws) Domain specificity of SP	Practical applications	Modelling Experimentation Making abstract concepts concrete	Gathering data Observation Discussion Predictions Hypothesis testing Modelling	

Table 4.1. Codes obtained from the visual representation for each case.

Cases/ Categories	Aylin	Beren	Deniz	Leyla
SP-Post	One directional circular diagram Nature Experimentation Observation Classification Questioning Modelling, Discussion Reasoning	BRH Observation Model Data Explanation Real world Prediction Scientific activities	BRH Model Explanation Data Prediction Real world Scientific activities	BRH Prediction Modelling Real world Explanation Scientific activities data Reasoning Discussion
M-Pre	Domain specificity of M (for different branches)	Step-by-step (the lock-step method) Asking a question doing research Constructing hypothesis Testing hypothesis Analyzing data reporting results	A step-by-step process (the lock-step method)	Hypothesis testing Manipulation Observational methods
M-Post	Brandon's matrix Hypothesis testing Manipulation Observation Explanation Scientific research	Hypothesis testing Not-hypothesis testing Manipulation Non-manipulation	Brandon's matrix Hypothesis testing Not-hypothesis testing Manipulation Non-manipulation	Brandon's matrix Hypothesis testing Not-hypothesis testing Manipulation Non-manipulation

Table 4.1. Codes obtained from the visual representation for each case.

Cases/ Categories	Aylin	Beren	Deniz	Leyla
SK-Pre	Interrogative nature of SK	Tentative nature of SK	Step-by-step process (the lockstep method) Transformation of theories into laws	Hypothesis Theories Laws Models
SK-Post	TLM Differences between TLM	TLM Differences between TLM	Development of SK Transformation of theories into laws	TLM Cumulative development of SK
SI-Pre	Universities Ministries Governments	Objectivity	Cultural beliefs and values Social institutions Certification of science	Ethics Political values Financial issues Social relations Social values social organizations
SI-Post	TUBİTAK CERN Political factors Academic journals Theses Research Economic needs	TUBİTAK NASA Research center Political power structure Publishing research Financial systems	TUBİTAK NASA Political power structure	Scientific values Social values Political factors Professional activities Social certification and dissemination Financial factors Social organization and interactions

4.1.2. Results of the Individual Interviews

This section presents the findings of the second sub-research question of the first primary research question, which is "How does the RFN-based online reflective and collaborative PD program influence science teachers' perceptions of the NOS?" The categories' codes for each case are shown in the tables. Teachers' suggestions for teaching each category of RFN are also coded and included in the table. Relevant quotations are provided for each sub-category of RFN.

4.1.2.1. Case 1 – Aylin's NOS Perception. Teacher Aylin's perception about NOS developed after participating in the PD program. The following section presents her developmental process, comparing pre- and postcodes and quotations for each RFN category.

Aylin's Perception of the Aims and Values of Science

In her pre-interview, teacher Aylin emphasized AV with the issues of validation of scientific knowledge, explanation, advancement of humanity, and questionability (see Table 4.2). In her pre-interview, she focused on the advancement of humanity as the main AV of science. She suggested focusing on teaching cumulative scientific knowledge and providing examples of technological progress with scientific knowledge to develop students' perception about the aims and values of science.

Table 4.2. Aylin's pre- and post- codes from the interviews on the AV of RFN.

	Pre-Codes	**Post-Codes**
AV	Validation of scientific knowledge Explanation Advancement of humanity Questionability	Ethical values Honesty Questionability Objectivity Decentralized power
Teaching AV	Teaching cumulative development of SK Linking technological progress with SK	Giving examples from the history of science Discussing characteristics of scientists

After participating in the PD program, Aylin mentioned ethical values, objectivity, honesty, and questionability (not being affected by gender, religion, political beliefs, etc.) as

the core values of science. She provided examples from the history of science, such as the DNA model of Watson and Crick, to teach these aims and values in science lessons. According to her, discussing the characteristics of scientists through diverse cases can also help students develop an understanding of the values of science. Aylin said:

> "I think of ethical values, the ability to be questioned, independence from centralized authority, and freedom from influences such as sexism, religion, or political bias come to mind… For instance, while teaching 8th graders about the structure of DNA, the significance of Wilkins and Franklin's contributions can be highlighted. Their research was later used by Watson and Crick, leading to their Nobel Prize win. Much later, the contributions of Wilkins and Franklin to the DNA model were finally acknowledged. This serves as a strong example of the importance of honesty in science. By presenting examples of scientists' work and creating case studies featuring individuals with diverse values, these principles and values of science can be effectively conveyed." (Aylin, post-interview)

As demonstrated in this excerpt, after participating in the PD program on NOS, Teacher Aylin places greater emphasis on the aims and values of science. It can be inferred that the PD program had a significant impact, particularly during the AV workshop, where they discussed two cases regarding scientists' attitudes—one exemplifying a focus on scientific aims and values, and the other neglecting them. Furthermore, her suggestions for teaching AV showed notable improvement. Before the intervention, she recommended teaching the development of scientific knowledge and provided examples of everyday products developed through scientific research. However, after the intervention, she offered examples that explicitly referenced scientific aims and values.

Aylin's Perception of the Scientific Practices

Before the intervention, Teacher Aylin viewed scientific practices as scientific processes, scientific methods, research methods, and reporting findings (see Table 4.3). She highlighted the diversity of scientific practices across different disciplines, emphasizing variations in knowledge production, measurement, and interpretation methods. She explained how natural sciences like physics, chemistry, and biology use distinct tools and approaches compared to social sciences, which employ methods like Likert scales. Common concepts such as dependent and independent variables were recognized as shared elements of the scientific process across disciplines. The teacher's answer regarding scientific practices is here:

> "When I think of SP, the fact that knowledge production doesn't always follow the same method comes to my mind. E.g., the knowledge in physics, chemistry, and biology involves specific practical applications and measurement methods. Social sciences, on the other hand, use different tools, such as Likert scales and other measurement and interpretation methods. When I think of SP, I think of a purpose-driven, applied system… For example, when students begin writing experiment results or interpreting experiments, though this isn't part of the curriculum, I push them a bit further—I tell them about dependent and independent variables. I explain that these concepts exist in almost all sciences…The words we use during experiments are part of this. I explain the scientific process, how we use these concepts in it, and how they represent our approach…" (Aylin, pre-interview)

Teacher Aylin emphasized the importance of scientific practices in education, with students being introduced to these concepts during activities such as writing and interpreting experiment results, even if they are not explicitly included in the curriculum.

Table 4.3. Aylin's pre- and post- codes from the interviews on the SP of RFN.

	Pre-Codes	**Post-Codes**
SP	Scientific processes Scientific methods Research methods Reporting findings	BRH Experimentation Observation Classification Modelling Discussion Real world Explanation
Teaching SP	Emphasizing scientific methods Distinguishing social vs scientific disciplines Reporting experiment results	Conducting experiment Teaching SP holistically

After the intervention, teacher Aylin highlighted the iterative and interconnected nature of scientific practices, emphasizing that knowledge builds progressively through repeated experimentation rather than through single trials. She pointed out the importance of understanding variable relationships, embracing a diversity of ideas, and recognizing the role of collaboration in enriching scientific discovery. Teacher Aylin also discussed the elements of Benzene Ring Heuristics, which include experimentation, observation, classification, modeling, discussion, and real-world application. Lastly, she stressed the need to teach scientific practices holistically and suggested incorporating these concepts more deeply into the curriculum as:

> "… When I think of scientific practices, I imagine a process that progresses where previous knowledge leads to the next… I also recall the benzene ring analogy. What was in it? Experimentation, observations, real world, classification, modelling, discussion and so on… We also applied these practices during workshops. The idea of repeating an experiment multiple times has always stuck with me—repetition is essential. These concepts might all lead to the same point, as multiple experiments allow for explanations and interpretations. I think it's better to teach these practices as a whole rather than individually…" (Aylin, post-interview)

Teacher Aylin emphasized the iterative and interconnected nature of scientific practices. She highlighted how scientific knowledge builds progressively, with previous discoveries paving the way for new insights. Additionally, she focused on key elements of BRH. According to her, workshops provided practical applications for teaching these practices. Thus, she believed that teaching scientific practices as an integrated whole is more effective than addressing them as isolated components, promoting a holistic understanding of the scientific process.

Aylin's Perception of the Scientific Methods and Methodological Rules

Teacher Aylin discussed the interconnectedness of scientific methods and practices, highlighting that both lead to similar conclusions and support each other. She viewed scientific methods as a one-directional, step-by-step process that begins with identifying a problem, conducting theoretical research, forming a hypothesis, and then testing it to either prove or disprove it (see Table 4.4). According to her, the techniques used in different scientific disciplines, such as physics and chemistry, vary, and these differences should be emphasized during teaching. However, due to her students' lack of foundational knowledge, she simplified the explanation of these methods for better understanding. Her perspective is expressed as:

> "For me, scientific methods and practices are quite similar; they lead to the same outcome and support each other. When I think of scientific methods, it involves a process: the formation of a problem, researching the problem, conducting theoretical research, forming a hypothesis after gathering theoretical information, testing the hypothesis, proving it if it's correct, or disproving it if it's wrong… For example, I tell students that the methods used in observing something physical are different from the methods used in a chemical experiment. I point out, "Do you remember the experiment we did? See how different its interpretation was? Look at how different what we did was." Of course, since the students don't have this foundational knowledge, I have to simplify it a bit for them." (Aylin, pre-interview)

Teacher Aylin explained that scientific methods and practices are closely linked, as they support each other and lead to similar conclusions. It can be said that Teacher Aylin has

a limited understanding of diverse scientific methods. On the other hand, she emphasized teaching various methods across disciplines, such as physics and chemistry, in classrooms.

Table 4.4. Aylin's pre- and post- codes from the interviews on the M of RFN.

	Pre-Codes	**Post-Codes**
M	Domain specificity of M (for different branches) Step-by-step method Identifying a problem Conducting theoretical research Forming a hypothesis Testing hypothesis to either prove or disprove it	Brandon Matrix Manipulation, Hypothesis testing Observation
Teaching M	Asking questions about scientific methods Teaching domain specificity of M	Asking questions about scientific methods Integrating scientific methods into science context Conducting experiments

Teacher Aylin's perception of scientific methods developed significantly. After participating in the PD program, she mentioned Brandon's matrix, which highlights whether scientific methods include manipulation or hypothesis testing. She emphasized the diverse nature of scientific methods, noting that some experiments allow for hypothesis testing, while others, like planetary models, focus on observation because of the inability to manipulate variables. Practical experiments, such as determining boiling points or phase transitions, enable variable manipulation. She presented her ideas in the following way:

> "When I think of scientific methods, the Brandon Matrix comes to my mind…In some experiments, hypotheses can be tested, while in others, they cannot, as not all studies can follow a single format. For example, when discussing planetary models, we can't manipulate certain elements. However, in an experiment to find the boiling point of water or the phase transition temperatures of pure substances, variables can be manipulated. It's about testing something or, in some cases, not testing at all—more like research or literature reviews… How can we teach this? For instance, when students examine experiments, they might ask, "Can we also do this?" I explain, "We don't have the means to do that right now; we can only observe." Perhaps these experiments could be presented in more detail. For example, in the 5th grade, many aspects of Galileo's work are mentioned, but they are summarized in just a few sentences. Instead, more emphasis could be placed on observation, and such topics could be integrated into the curriculum. Similarly, in 5th and 6th grades, when studying phase transitions and the phase transition temperatures of pure substances, students could analyze variables through related experiments. I believe some M could be better explained here." (Aylin, post-interview)

Teacher Aylin emphasized the importance of integrating observation-based learning and detailed explanations into the curriculum, particularly for topics like Galileo's work or

phase transition studies in 5th and 6th grades. She suggested improving how scientific methods are taught by encouraging hands-on analysis and deeper exploration of key experiments.

Aylin's Perception of the Scientific Knowledge of Science

Before the intervention, teacher Aylin viewed scientific knowledge as testable, falsifiable, refutable, or verifiable (see Table 4.5). She indicated that a subjective statement is not acceptable as scientific knowledge; it should be tested through experiments and constructed hypotheses. According to Aylin, the knowledge development process begins with curiosity and continues with scientific methodology based on theoretical knowledge. She did not explicitly mention how she teaches scientific knowledge in her lessons.

Table 4.5. Aylin's pre- and post- codes from the interviews on the SK of RFN.

	Pre-Codes	**Post-Codes**
SK	Falsifiability Verifiability Hypothesis testing Empirical evidence Curiosity and questioning Importance of the scientific method Skepticism and critical thinking	TLM Differentiation between theories and laws Cumulative development of SK Universal language Scientific understanding
Teaching SK	Encouraging curiosity in students Fostering reasoning and critical thinking	Incorporating complex theories at appropriate levels. Introducing students to the processes of SK Using relatable examples to explain abstract concepts

After the intervention, Teacher Aylin differentiated various types of scientific knowledge. She emphasized the interconnected roles of theories, laws, and models in building scientific understanding. Laws provide generalizable knowledge, theories explain them and generate ideas, and models make abstract concepts tangible. According to her, teaching this process—through topics like thermodynamics or specific heat—and discussing experiments and discoveries can help students grasp how science evolves. Her perspective is expressed as:

> "That is, theory, law, the entirety of scientific understanding, and modelling. These were scientific knowledge. The content of this SK wasn't entirely and absolutely proven, which is why it became a law. In fact, laws were generalizable knowledge. The sub-knowledge that explained these laws and generated new ideas constituted theories. Since what each piece of knowledge presented might be things that cannot be observed with the naked eye or through the five senses, turning them into three-dimensional or material forms was what we called modelling, or a model. These elements actually supported one another and formed a structure as a whole. We called this whole scientific understanding. I never forget this. … There is generalizable knowledge, such as Newton's laws of motion. Each study, each new experiment, and each new finding related to this creates theories. These theories essentially form the bricks of that wall, that structure, that house. Among these findings, making something three-dimensional and observable constitutes modelling, as far as I know. …." (Aylin, post-interview)

Aylin's Perception of the Social-Institutional Aspects of Science

Teacher Aylin viewed the SI as a human-related field, while considering the institutional aspects of science as bureaucracy. However, she expressed that she doesn't know the SI; they are merely predictions. Teacher Aylin suggested that in her teaching, she prefers to discuss scientific institutions such as universities. She articulated her thoughts as follows:

> "The social aspect of science is the part that involves people. The institutional aspect, on the other hand, seems more like the bureaucratic side to me. But I have no knowledge about this at the moment. These are the meanings it evokes for me. It's as if science has a bureaucratic side and a side that involves humanity and individuals. The part involving individuals is social, while the bureaucratic side could be institutional. In classes, topics like universities and institutions conducting scientific research could be discussed." (Aylin, pre-interview)

Table 4.6. Aylin's pre- and post-codes from the interviews on the SI of RFN.

	Pre-Codes	**Post-Codes**
SI	Humanity Bureaucracy	Social dissemination (sharing knowledge with society and scientists) Financial systems (etc. materials) Political power structures Social organizations
Teaching SI	Mentioning about institutions that make scientific works (e.g. universities)	Teaching through questioning via discussion Teaching through giving examples from Türkiye and Turkish government

After attending the PD program, Teacher Aylin enhanced her understanding of SI and highlighted various categories of SI, including social certification and dissemination, financial systems, political power structures, and social organizations. She noted that scientists are affiliated with certain institutions and are responsible for sharing knowledge with society and other scientists. To teach SI to students, Teacher Aylin recommended using

questioning and discussion techniques and providing examples from Türkiye and the Turkish government. For instance, she expressed that space research in Türkiye and the Turkish government's support for this research could be explained to students. Her perspective is expressed as:

> "It's about scientists obtaining knowledge under certain institutions and then sharing it with both society and the scientific community, disseminating it, using appropriate channels, providing the materials needed for experiments and observations, ensuring the economic conditions required for these, and sometimes even using this scientific knowledge in political contexts or being dependent on the state... E.g., why should scientists share their findings? How should they share them? Questions like, 'To what extent does the state benefit from these, or how much does the state support them?' …." (Aylin, post-interview)

4.1.2.2. Case 2 – Beren's NOS Perception. The NOS improved after her participation in the professional development (PD) program. The next section outlines her development by comparing the pre- and post-intervention codes and quotations within each RFN category.

Beren's Perception of the Aims and Values of Science

The interview results show that Beren focused on different issues in her pre- and post-interviews (see Table 4.7). Before the intervention, Teacher Beren highlighted the themes of ethical values, honesty, serving humanity, the development of scientific knowledge, and universality as the aims and values of science. She mainly emphasized the universality and ethical progression of science as its core values and purpose. She highlighted that science is for all humanity, contributing to universal knowledge and progress. In her teaching, she stressed the unchanging and universal nature of scientific language, using examples like the classification of living organisms. However, she acknowledged that she has not extensively addressed scientific values in her lessons so far.

After participating in the PD program, Teacher Beren associated the AV of science primarily with ethical and moral principles, focusing on how science should be conducted and the responsibilities it entails. She highlighted essential values such as empirical adequacy, dissemination of scientific knowledge, and universality, along with the characteristics that scientists should embody. She suggested teaching these values either as a separate topic or by emphasizing the universality and iterative progress of science within

various units, such as the 5th grade science 'Living World' unit. Teacher Beren also underscored that science evolves cumulatively, corrects itself, and has a tentative nature as:

Table 4.7. Beren's pre- and post- codes from the interviews on the AV of FRN.

	Pre-Codes	**Post-Codes**
AV	Ethical values Honesty Serving to humanity Development of scientific knowledge Universality	Ethical and moral values Characteristics of scientists Empirical adequacy Dissemination of SK Universality
Teaching AV	Teaching universality of science Do not know how to teach AV	Teaching AV through horizontal articulation Teaching cumulative development of SK Teaching tentative nature of SK

> "The AV of science completely reminds me of moral and ethical values. In other words, how can science be applied ethically and morally? What should it possess? What values and responsibilities does it have? … For instance, there are qualities that a scientist should have, such as experimental competence, sharing, and universality… These values can be taught as a completely separate topic or emphasized in every unit by focusing on the universality of science and the characteristics of scientists. For example, in the 'Living World' unit, we explain how scientists initially classified living things and how the process has evolved over time. At each new stage, we highlight what scientists universally accepted and what they identified as incorrect and then changed. We can emphasize that there is no single truth in science; rather, science progresses cumulatively and through self-improvement." (Beren, post-interview)

The interviews revealed that Teacher Beren's perception of the AV of science evolved after the PD program. Initially, she focused on themes such as ethical values, honesty, universality, and serving humanity, emphasizing the consistent and universal nature of scientific language. While she acknowledged these principles, she admitted that she did not extensively incorporate them into her teaching. After the PD program, her perspective deepened. She advocated for explicitly teaching these values, either as standalone topics or integrated into units, concentrating on the same unit (Living organisms) with more sophisticated aspects. This shift indicated the positive impact of the PD program on enhancing her perception of teaching the AV of science.

Beren's Perception of the Scientific Practices

Before participating in the PD program, Teacher Beren viewed scientific practices as experimentation and observation, applying them in practice. However, she admitted that she had not yet addressed this aspect in her lessons (see Table 4.8). She expressed her views as:

> "When I think of scientific practices or applications... What comes to mind is conducting an observation or experiment and putting it into practice. Have I addressed scientific applications in my lessons? As far as I can recall, I don't think I've covered that aspect of scientific applications yet." (Beren, Pre-Intervention)

Table 4.8. Beren's pre- and post- codes from the interviews on the SP of RFN.

	Pre-Codes	**Post-Codes**
SP	Experimentation Observation	Gathering data Observation Modelling Prediction Experimentation Scientific activities Inferences Real world
Teaching SP		Visualizations of scientific concepts Active student participation Integration of SP in Lesson Planning Linking SP to everyday life Designing and conducting experiments

The teacher connected scientific practices with activities such as data collection, observation, making predictions, modeling, conducting experiments, and analyzing data after the intervention (see Table 4.8). She emphasized the importance of these practices in education, as highlighted by the national curriculum, although it notes limitations in time and resources for thorough implementation. The teacher outlined methods for teaching these practices, such as engaging students in experiments, encouraging predictions, designing setups, collecting data using tables or graphs, and relating experiments to real-life problems. She believed that scientific practices are well-suited for active learning and could be better integrated into lessons with additional time and resources. She articulated her thoughts as follows:

> "When I think of SP, what comes to mind are applications. I believe the English term is "practice," which translates to "application" in Turkish. Scientific applications include activities like data collection, observation, creating models based on predictions, making predictions, and conducting experiments as part of scientific activities… The Ministry of National Education places great importance on these application aspects as well. For example, students observe experiments, make inferences from experimental results, collect data, and analyze the data—these are part of the learning objectives... We almost always include an experiment in each topic. In these experiments, I might ask students to predict how the experimental materials can be used or to make predictions about the outcomes related to the topic or problem. I could have them set up an experiment and make observations during the process. If the experiment involves a data collection phase, I might ask students to create tables or graphs to organize the data or design different materials for data collection. I could also ask them to identify a similar problem in daily life. This way, I believe experiments or observations can be used to engage students more actively." (Beren, post-interview)

It can be said that Teacher Beren's perception of SP developed significantly after participating in the PD program. She referenced almost every component of BRH and provided effective suggestions for teaching SP in science lessons.

Beren's Perception of the Scientific Methods and Methodological Rules

Teacher Beren viewed scientific methods as a one-directional, step-by-step process. She outlined this process as making observations, making predictions, conducting experiments, testing hypotheses, and solving problems (see Table 4.9). The teacher remembered referencing Galileo's experiments in class, presenting them as a narrative to illustrate the scientific methods and enhance understanding. She expressed her ideas as:

> "A specific diagram immediately comes to mind, teacher. It starts with observation, followed by making predictions, conducting experiments, and forming a hypothesis. If the hypothesis isn't supported by the experiment, it is revised, and the experiment is repeated until the problem is solved. Have I mentioned this in my lessons? As I said, I started by talking about Galileo Galilei's experiments. I presented them as a narrative, like, 'He wonders, why is this happening?' I think this can be considered an example." (Beren, Pre-Interview)

Before the intervention, Teacher Beren had a naive understanding of scientific methods. She confused scientific methods with research methods. According to the teacher, all scientific methods involve experiments and hypothesis testing.

After the intervention, the teacher linked scientific methods to the Brandon Matrix, which includes manipulation and non-manipulation, as well as hypothesis testing and non-hypothesis testing methods. She provided various examples for different scientific methods. On the other hand, she believed that students can fully grasp these concepts around 7th grade,

although the concept of "variable" should be introduced in earlier grades (5th and 6th) to build a foundation. However, the current curriculum lacks sufficient space to thoroughly address these topics, and the teacher suggested creating a separate unit that includes diverse examples to teach scientific methods more effectively. She explains her thoughts as follows:

> "When thinking about scientific methods, what comes to mind are the theoretical concepts I learned, particularly the Brandon Matrix. This includes experiments with variable manipulation, observations without altering variables, and discoveries through serendipity or observation, like studying space or the surroundings. I associate this with the structured rules of the Matrix, where methods intersect based on variable manipulation and hypothesis testing. I believe students can grasp this fully around 7th grade, as their cognitive levels develop further. While variable concepts should be introduced in 5th and 6th grades with examples, they may not fully understand until later. To teach this effectively, a separate unit focusing on diverse examples, as demonstrated in our training, would be ideal. However, the current curriculum lacks sufficient room to address these topics deeply, offering only a few units where variables are even discussed." (Beren, post-interview)

It can be concluded that after the intervention, teacher Beren's perception of scientific methods and her suggestions for teaching these methods improved. She recognized the diverse scientific methods used in science and how she can teach these methods in her lessons.

Table 4.9. Beren's pre- and post- codes from the interviews on the M of RFN.

	Pre-Codes	**Post-Codes**
M	Observation Experimentation Hypothesis testing Solving problem	Brandon matrix Manipulation Non-manipulation Hypothesis testing Not-hypothesis testing
Teaching M	Referring to history of science	Teaching variables Teaching observational methods Paying attention to students' grade levels

Beren's Perception of Scientific Knowledge

Before participating in the PD program, Teacher Beren focused on the tentative nature of scientific knowledge and the cumulative development of scientific knowledge (see Table 4.10). She described different types of scientific knowledge as quantitative and qualitative. For her, she already teaches scientific knowledge in her science lessons, but she has not addressed the tentative nature of science. She expressed her ideas as:

"When I think of scientific knowledge, I think of information that is changeable, improvable, and expandable. I do talk about this in my lessons, of course. We already provide scientific knowledge to the students. However, I haven't really mentioned to them that scientific knowledge can change, improve, or even be completely reversed in ten years. Apart from that, everything we teach is already scientific knowledge. Types of scientific knowledge... There must be some, of course, but I can't quite recall the types of scientific knowledge at the moment. Perhaps quantitative or qualitative knowledge exists. I hadn't mentioned or addressed this in my lessons." (Beren, pre-interview)

Table 4.10. Beren's pre- and post- codes from the interviews on the SK of RFN.

	Pre-Codes	**Post-Codes**
SK	Tentative nature of SK Cumulative development of SK Quantitative knowledge Qualitative knowledge	TLM (Theories, laws and models) Differences among TLM
Teaching SK	Teaching science itself	Teaching differences among theories, laws and models Teaching tentative nature of science, Teaching paradigm change Selecting appropriate science issue referring to SK Paying attention to students' cognitive levels

Teacher Beren described theories, laws, and models as different types of scientific knowledge after participating in a PD program. She mentioned the functions of each kind of scientific knowledge, emphasizing that there is no hierarchy among them. According to Teacher Beren, while scientific knowledge is present in all topics, its complexity often exceeds students' cognitive levels, particularly in middle school. Topics like electricity, atoms, and the periodic table can introduce scientific concepts, but high school subjects like physics, chemistry, and biology are more suitable for deeper exploration. Understanding scientific knowledge requires examples and emphasizes the dynamic, evolving nature of science, reflecting its adaptability through paradigm shifts and continuous advancements. She explained her thoughts as follows:

"When I think of SK, the idea of its many different types comes to mind. I also think about how there is no hierarchy among these types. Theory, law, and model are examples of scientific knowledge types, and there is no hierarchy among them either. Each serves a different purpose, or rather, they represent different types of knowledge. For instance, a law explains what an event or phenomenon is, while a theory explains how or why it happens. …. A model as scientific knowledge explains something, allowing us to gain insights and make inferences from it. While SK exists for all topics, students' cognitive levels are not always sufficient to grasp it. In 7th grade, there's the atom unit, and in 8th grade, the periodic table. We can talk about theories and laws…" (Beren, post-intervention)

Beren's Perception of the Social-Institutional Aspects of Science

Teacher Beren emphasized the social conditions that affect scientists' studies when she was asked about the SI. In her teaching, she prefers to focus on the lives of scientists (e.g., Tesla, Galileo) and the influence of environmental conditions on their work.

Table 4.11. Beren's pre- and post- codes from the interviews on the SI of RFN.

	Pre-Codes	**Post-Codes**
SI	Social conditions that affect scientists' studies	Serving to humanity Publication Collaboration among scientists Financial supports Social organizations The impact of government on science The impact of religion on science The impact of politics on science The impact of social values on science Professional activities (writing and publishing articles, meetings among scientists)
Teaching SI	Teaching scientists' lives (e.g. Tesla, Galileo) Teaching the effects of conditions on scientists	Teaching through texts by creating discussion Curriculum flexibility Teaching through debates Teaching through videos

After participating in the PD program, Teacher Beren's perceptions of the SI developed. She mentioned studies conducted by scientists that serve humanity. Additionally, she emphasized publication, collaboration among scientists for publication, and financial support for publication. Social organizations such as NASA, TÜBİTAK, research institutions, and universities are other key points that Teacher Beren focused on. She also considered the impact of government, religion, politics, and social values on science related to the SI. Moreover, she pointed out some professional activities such as writing and publishing articles, and meetings among scientists. Teacher Beren believes that the SI is mostly related to discussion, so she suggests using texts at the end of the units to facilitate discussion. Furthermore, she proposes teaching the SI through debates and videos. She stated her views as:

> "… the work scientists do for humanity, the publication of their research, the collaborative publications they produce, and the support they receive to create these publications. Institutions established to advance science, such as NASA, TÜBİTAK, research institutes, and science faculties and institutes at universities, also come to mind… Science is, of course, an independent phenomenon, but the people who develop it are still human beings like us, and these individuals inevitably have social lives and a need to be accepted by society. The factors that most affect this need are, let's not say politics, but the government, policy, religion, and the ethical values of the society in which they live. … In science courses, this topic is better explained through discussion. ... Similarly, I think this could be taught by giving texts, holding discussions and debates, and showing related videos. The activities scientists engage in—writing articles, publishing them, and attending meetings—are what come to my mind. Beyond that, I can't think of anything else, teacher." (Beren, post-interview)

4.1.2.3. Case 3 – Deniz's NOS Perception. After participating in the PD program, Teacher Deniz's understanding of each component of the RFN advanced. The following section details her progression by comparing pre- and post-intervention codes and excerpts for each RFN category separately.

Deniz's Perception of the Aims and Values of Science

Before participating in the PD program, teacher Deniz described the AV of science with themes of sustainability, serving humanity, and the development of scientific knowledge (see Table 4.12). For her, the main purpose of science is to serve humanity, and she emphasized the need to convey this purpose to her students. She made connections with concepts regarding the nature of scientific knowledge, such as certainty, changeability, and the relationship between laws and theories, but admits she rarely, if ever, addresses these topics in her science lessons. She also acknowledged a personal gap in fully understanding and teaching the aims of science. In her pre-interview, she presented her ideas in the following way:

> ".... I see this as a personal shortcoming, recognizing a gap in my own understanding of the aim of science. I wonder how my perspective might change as I reflect further on this. As for the AV, what comes to mind are questions like: Is it absolute? Can it change or remain unchanged? Can a law become a theory? Is a theory definitive? These are the kinds of concepts I associate with the values of science. In my science lessons, I don't really touch on these ideas." (Deniz, pre-interview)

It was observed that while Teacher Deniz recognized some aims and values of science, her understanding was limited, as she struggled to provide specific examples. Instead, she asked questions that came to mind. Furthermore, she seemed to hold a misconception that theories evolve into laws before participating in the PD program.

Table 4.12. Deniz's pre and post codes from the interviews on the AV of RFN.

	Pre-Codes	Post-Codes
AV	Sustainability Serving to humanity Development of scientific Certainty	Epistemic, cognitive and social values Teaching the reasons of learning of science Serving to humanity Linking technological progress with SK Understanding nature
Teaching AV	Teaching the reasons of learning of science Teaching tentative nature of science Do not know how to teach AV	Giving examples from the history of science Teaching tentative nature of science Teaching cumulative development of SK Teaching through videos and documentaries Teaching by going science museums

After participating in the PD program, Teacher Deniz discussed additional themes and provided more specific examples. These included epistemic, cognitive, and social values, teaching the reasons for learning science, serving humanity, linking technological progress to scientific knowledge, and understanding nature. Once again, she emphasized that serving humanity is the primary AV of science. It was observed that her perception developed to a limited extent following the intervention. Unlike her pre-interview responses, she categorized AV separately, provided several examples, and made thoughtful teaching suggestions. However, the range of themes she addressed, such as epistemic, cognitive, and social aims and values, remained narrow. She expressed her thoughts as follows:

> "The aims and values of science, in my view, involve understanding why scientific knowledge needs to be discovered, why it should be taught, and how it benefits humanity. For instance, we have developed a washing machine as a technological advancement, which benefits humanity. Similarly, the discovery of penicillin has brought great benefits to people… I also see science as a means of understanding and interpreting nature. It brings to mind epistemic, cognitive, and social values… E.g., we could show videos, screen documentaries, or even organize museum visits to help students engage more deeply with science…" (Deniz, Post-interview)

On the other hand, as seen in the quotation above, her teaching suggestions demonstrated significant development. She proposed incorporating examples from the history of science, emphasizing the tentative and cumulative nature of scientific knowledge, utilizing videos and documentaries as teaching tools, and organizing visits to science museums.

Deniz's Perception of the Scientific Practices

Teacher Deniz viewed SP as hands-on applications, particularly observations and experiments (see Table 4.13). Rather than merely stating scientific concepts, she believed in demonstrating them practically. For example, she prefers to show her students gravity by dropping an object. Similarly, instead of explaining acid-base reactions, she demonstrates the reactions in action. She believes that hands-on learning, where students actively engage and observe, makes concepts more memorable and impactful. She also emphasized the importance of revisiting past experiments to reinforce learning and ensure that the experience stays with the students. She illustrated her ideas as:

> "SP are applications. This concept always brings experiments to mind for me. It's the classic method allowing the child to experience something directly through hands-on learning. It's not just saying, 'Gravity exists.' It's showing them, 'Look, I dropped this, and it fell.' It's practical… When I think of applications, these are the types of things that come to mind: concrete demonstrations of abstract concepts. I emphasize this in my teaching. I apply it directly, and once we've done the application, we continually revisit it. 'What did we do last time?' … Since the students experience it themselves, I believe that application, rather than words, is what stays with them." (Deniz, Pre-intervention)

In conclusion, the teacher highlighted that scientific practices are best learned through hands-on applications. Rather than merely explaining abstract concepts, the teacher preferred to demonstrate them through experiments, enabling students to experience and observe the concepts directly.

Table 4.13. Deniz's pre and post codes from the interviews on the SP of RFN.

	Pre-Codes	**Post-Codes**
SP	Hands on application Observation Experimentation	BRH Real world, Model, Data Classification, Observation, Experimentation
Teaching SP	Doing hands on activities Directing questions about their experiences	Making connection to SP Asking questions about SP Using BRH

The teacher explained that scientific practices are interconnected, much like a benzene ring heuristic. Concepts such as the real world, scientific practices, models, data, classification, observation, and experimentation are all linked (see Table 4.13). The teacher

believed that students could understand and apply these practices when taught clearly and through hands-on examples. For instance, when students create models like atoms or DNA, they are engaging in modeling. The teacher also suggested using the Benzene Ring analogy to assess and enhance student awareness, inviting them to reflect on whether they made observations, classifications, created models, or conducted experiments during lessons. She expressed her views as:

> "When I think of SP, the benzene ring analogy comes to my mind. I think of the real world, scientific activities, modelling, research, data, classification, observation, and experimentation. It seems like I've studied well. In the benzene ring analogy, I found it very easy to integrate these elements. It's the easiest in this context. E.g., did we conduct any research or classification today? Did we make any observations? Were these integrated into the real world? Did we create a model or develop a representation of something? Did we provide explanations? These are the things that come to mind, and I see them as interconnected... If teachers serve as facilitators in this regard, we could assess a topic using this benzene ring analogy. For instance, we could include it in our evaluations and ask students, "Which of these practices do you think we engaged in? … Where and how did we do these?" (Deniz, post-interview)

After the intervention, Teacher Deniz enhanced her understanding of scientific practices. She began to consider other scientific practices, such as modeling, classification, experimentation, and explanation, and emphasized the benefits of a holistic approach to teaching these practices. She also provided effective strategies for teaching SPs.

Deniz's Perception of the Scientific Methods and Methodological Rules

Before the intervention, Teacher Deniz viewed scientific methods as a step-by-step process that begins with constructing a hypothesis, testing that hypothesis, altering it if necessary, determining variables, and conducting an experiment (see Table 4.14). According to her, she strives to connect these concepts to teach scientific methods in her lessons. She expressed her ideas as:

> "When I think of M, what comes to mind is first forming a hypothesis, then testing it, and if it turns out to be incorrect, revising the hypothesis. Identifying variables is also important—dependent, independent, and controlled variables. In my lessons, we identify the variables, conduct experiments, and observe the changes. E.g., if we consider factors affecting the rate of solubility, we observe whether increasing the amount of sugar changes the dissolution rate. The students observe, we identify the variables and form our hypothesis. If our hypothesis turns out to be correct, I emphasize that the method we applied is valid." (Deniz, Pre-Interview)

Before participating in the professional development (PD) program, Teacher Deniz had a limited understanding of scientific methods. She believed that all scientific methods involved manipulation and hypothesis testing. For example, she shared instances from her lessons where she teaches about variables during experiments and asks her students questions to help them learn about scientific methods.

Table 4.14. Deniz's pre and post codes from the interviews on the M of RFN.

	Pre-Codes	**Post-Codes**
M	One directional step by step method Constructing hypothesis Testing hypothesis Re-constructing hypothesis	Brandon matrix Manipulation Non-manipulation Hypothesis testing Not- hypothesis testing
Teaching M	Conducting experiments Identifying variables	Using Brandon's matrix Using diverse scientific methods Discussion on diverse scientific methods

After the intervention, Teacher Deniz shifted her focus to Brandon's Matrix. She explained four types of scientific methods: manipulation with hypothesis testing, manipulation without hypothesis testing, non-manipulation with hypothesis testing, and non-manipulation without hypothesis testing. She also provided examples for each category, drawing from the content of the PD program. Furthermore, her approach to teaching scientific methods evolved. She emphasized the importance of asking questions about scientific methods, integrating Brandon's matrix into her lessons, and using historical examples from science to engage her students. She shared her perspective in these words:

> "It reminds me of Brandon's matrix. Brandon proposed four categories: testing a hypothesis with variable manipulation, testing a hypothesis without variable manipulation, manipulating variables without testing a hypothesis, and neither testing a hypothesis nor manipulating variables…. These examples illustrate the four categories and helped address our misconceptions, showing that not everything in science is tested. We learned that some scientific knowledge doesn't require testing. In our science lessons, e.g., when teaching a theory or conducting an experiment, we could integrate this by asking, "Do you think we conducted a test here? Did we form a hypothesis? Did we manipulate any variables?" … "Which of Brandon's four categories do you think was used here? This could foster meaningful exchanges of ideas with our students." (Deniz, Post-interview)

It can be concluded that the PD program positively influenced Teacher Deniz's perception of scientific methods. She began to recognize the existence of various scientific methods and provided examples for each. Her suggestions for teaching scientific methods

also evolved, as she explicitly emphasized teaching Brown's Matrix and incorporating references to diverse scientific methods in her science lessons.

Deniz's Perception of Scientific Knowledge

Before the intervention, Teacher Deniz perceived that scientific knowledge is tested, proven, and largely accepted; it includes hypothesis testing and has a tentative nature (see Table 4.15). She could not explain its types but mentioned how it grows and develops, such as understanding buoyancy, which led to the development of rafts and ships. She made a connection to technology that scientific knowledge explored through research methods, as advancements spark new questions. She conveyed her ideas in the following manner:

> "When I think of scientific knowledge, I think of information that has undergone hypothesis testing, been proven, and is therefore accepted worldwide, though it is, of course, subject to change. I define scientific knowledge as the most recent, proven information that has gone through stages of validation, as you mentioned…. I think scientific knowledge grows and develops by building on every discovery. First, the concept of buoyancy was understood. After that, a raft was built. It developed further and became a ship…. As advancements are made, new curiosities arise, and by applying research methods to these questions, I believe SK evolves." (Deniz, pre-interview)

Table 4.15. Deniz's pre and post codes from the interviews on the SK of RFN.

	Pre-Codes	**Post-Codes**
SK	Proven knowledge Supported knowledge Tentative nature of SK Cumulative development of SK	TLM Differences among TLM Tentative nature of SK Cumulative development of SK
Teaching SK		Directing questions about differences among TLM Discussing tentative nature of SK Discussing cumulative development of SK

Teacher Deniz identified different types of scientific knowledge as TLM (theories, laws, and models), which are interconnected yet distinct. She emphasized the different functions of each. For instance, models, such as atomic models, are developed through experiments and inferences, and they can change over time. Theories explain how outcomes might occur. She suggested that teaching scientific knowledge can involve class discussions and questions, highlighting that scientific knowledge evolves through discoveries, peer review, and validation by institutions. She shares her perspective in these words:

> "When it comes to types of SK, what comes to mind are laws, theories, and models. I can say that laws and theories are different from each other yet interconnected, that scientific knowledge is subject to change, and that models can be created through various inferences and experiments. For example, the atom has not been directly observed, but a model was created through advanced experiments and inferences. Over time, atomic models have also changed. A theory, on the other hand, explains how certain outcomes could occur. We watched a video during training related to this topic. I think this concept can be integrated into our lessons with questions like, "Do you think we are dealing with a theory or a law right now? … What do you think we worked on?" We can also teach that scientific knowledge is subject to change. When something new is discovered, the old knowledge may be disproven, not randomly, but through reporting to relevant institutions or organizations. After passing peer review, it can turn into accepted knowledge. (Deniz, post-interview)

It can be concluded that after the intervention, Teacher Deniz's awareness of diverse types of scientific knowledge improved. She also suggested teaching SK explicitly.

Deniz's Perception of the Social-Institutional Aspects of Science

Teacher Deniz believed that SI relates to society's views on science. She also established a connection between SI and keywords like belief systems and mores. Additionally, Teacher Deniz emphasized social certification and dissemination as aspects of SI in science. During her teaching process, she stated that she doesn't mention SI explicitly, but she considers it when there's a relevant text in the coursebook.

Table 4.16. Deniz's Pre- and Post- codes from the interviews on the SI of RFN.

	Pre-Codes	**Post-Codes**
SI	Society The viewpoints of society toward science Belief system Mores Social certification and dissemination	Social values (e.g. serving to humanity, no harm, respect to each other, respect to environment) Social organizations (CERN, TÜBİTAK) Social certification (accepting or rejecting SK, investigation of SK with experts) Political power structures (Gender inequality) Financial systems Articles Organizing seminars Sharing knowledge (dissemination)
Teaching SI	Reading texts in the course books	Teaching through news to take attention of students Integration of SI to the lesson plans Restrictions to the science Teaching through articles and newspapers Teaching through discussion Teaching social organizations Organizing a trip to the social organizations

After the PD, Teacher Deniz provided details about the categories of SI, including social values, social organizations, social certification and dissemination, political power structures, and financial systems. She illustrated the social values category by discussing concepts such as serving humanity, doing no harm, respecting each other, and respecting the environment. Examples of social organizations included CERN and TÜBİTAK. Furthermore, she highlighted the importance of keywords related to accepting or rejecting SK, as well as the investigation of SK with experts for social certification, alongside the keywords related to gender inequality for political power structures. Additional keywords included articles, organizing seminars, and sharing knowledge. As a teaching implementation of SI, she recommended utilizing news, articles, and newspapers to capture students' attention and foster discussions. Teacher Deniz also suggested teaching about social organizations and interactions and organizing trips to various institutions. She presented her ideas in the following way:

> "When I think about the SI aspects of science, the values of science come to mind—conducting science for humanity, ensuring no harm is done in the process. Then, institutions and organizations come to mind. For example, social acceptance comes to mind. I also think of political power and financial power when you mention the social and institutional aspects. I remember when we discussed in your class the example of a woman whose invention couldn't progress because of sexism, how her work was blocked due to gender discrimination. That comes to mind. Or political power, like during Hitler's time, when advancements were made solely for war and national interests. Institutions and organizations like CERN and TÜBİTAK also come to mind. The importance of mutual respect and respect for the environment, which are part of the values of science, is another thing I think of. Other things that come to mind include writing articles, organizing seminars together, and sharing the knowledge discovered. One specific thought is about the acceptance of scientific knowledge by a peer review board—not all knowledge is accepted; it is evaluated by experts. These are the things I associate with the SI aspects of science. Actually, we could find news articles related to science and our topics, something both engaging and relevant for students. For example, bringing in a news article could make students think, *"Oh, are there such obstacles in science? Are there these other dimensions as well?"* Incorporating this into our lesson plans could both increase students' interest and raise awareness. It's not just about learning the other aspects of science but also recognizing, *"Look, there are these challenges too. This is how we should approach science and advance it. These are the powers we can change."* I believe raising awareness in our lessons is crucial. For instance, we could include articles or news pieces from newspapers related to our topics and have class discussions around them. We could provide information about institutions conducting scientific work and even organize field trips to such places." (Deniz, post-interview)

4.1.2.4. Case 4 – Leyla's NOS Perception. Teacher Leyla had prior familiarity with the RFN framework from her pre-service teacher education, which contributed to her strong initial understanding of each category. However, during the PD program, she had the chance to discuss and explore the sub-components of each category in greater depth. After the

intervention, her understanding became more sophisticated; she could provide more examples and demonstrated a more holistic way of thinking.

Leyla's Perception of the Aims and Values of Science

Teacher Leyla emphasized that the aims and values of science encompass epistemic, cognitive, social, and ethical dimensions (see Table 4.17). In her teaching, she addresses these aspects by prompting students to think critically about the purpose, impact, and ethical considerations of scientific work. For example, she encourages discussions on the aims of specific studies, their contributions to various communities, and ethical dilemmas such as using animals for research. Regarding social values, she mentioned the cultural, historical, and political contexts of scientific knowledge creation, questioning how and why certain discoveries occur in specific regions or under particular circumstances. It can be said that before the intervention she had a good level of understanding about the aims and values of science. She expressed her ideas as:

> "When I think about the aims of science, concepts like its epistemic and cognitive aspects come to mind... For example, I might ask, "What was the purpose of this study? … Who benefited from this study? Did it only benefit the region where it was conducted, or were other areas also impacted? Do you think this study was ethical? For instance, is it acceptable to develop medicine using animal testing? If not, what alternatives would you suggest?" … From a social perspective, I consider the environment in which scientific knowledge is created. Was the scientific knowledge supported socially and culturally during its formation? Was it influenced by the culture where it originated?" (Leyla, Pre-Interview)

Table 4.17. Leyla's pre- and post- codes from the interviews on the AV of RFN.

	Pre-Codes	**Post-Codes**
AV	Epistemic, cognitive and social values Ethical values Universality Serving to humanity Respecting environment, human and living thing Historical and political context	Universality Honesty Objectivity Decentralizing power Serving to humanity Accuracy Ethical values
Teaching AV	Teaching through questioning	Teaching through questioning via news, articles

Through discussions, she challenges her students to consider the societal support and cultural influences behind scientific advancements, such as how the launch of Sputnik impacted U.S. education policy. By posing questions and fostering dialogue, the teacher encourages her students to reflect on the broader implications of science in cultural, ethical, and political contexts. Thus, it can be said that Teacher Leyla has a good understanding of the aims and values of science at the beginning of the study.

After participating in the PD program, Teacher Leyla deepened her understanding of the aims and values of science. She emphasized key aspects such as universality, honesty, objectivity, decentralizing power, serving humanity, maintaining accuracy, and upholding ethical principles. She articulated her perspective on the aims and values of science as follows:

> "There is a path to follow, and on this path, there are certain principles to be observed. These are essential for a study to qualify as scientific. I view these principles in this way: objectivity, honesty, and universality. In other words, I perceive scientific research as a tool that should move beyond individual control and serve society. To achieve this, it is crucial not to manipulate data, to prefer ethical approaches, or rather, to pay attention to ethical considerations." (Leyla, Post-Interview)

Leyla believed that these values form the foundation of scientific inquiry and are crucial for fostering a deeper understanding of science in educational settings. To effectively teach the aims and values of science, she suggested incorporating articles, news, and real-world examples into teaching materials, as these often highlight these principles in action. Leyla emphasized the importance of using these resources to make abstract concepts tangible and relatable for learners, encouraging critical thinking and ethical reasoning.

Leyla's Perception of the Scientific Practices

Teacher Leyla demonstrated a strong understanding of scientific practices even before participating in the PD program. She identified all the components of BRH—data, discussion, prediction, observation, experimentation, modeling, explanation, social certification, and discourse (see Table 4.18). Additionally, she explained how each scientific practice could be effectively taught using specific science concepts. Her prior knowledge of scientific practices was largely informed by a course she took during her undergraduate

studies. This suggests that undergraduate coursework plays a significant role in shaping teachers' perceptions of NOS. She articulated her thoughts as follows:

> "I can list many things—activities that can help me both access and evaluate scientific knowledge. For example, analyzing and interpreting data, discussing information, or making predictions. Prediction, observation, and experimentation are also essential. Then there's modelling. For instance, if we cannot observe something, like phenomena related to space, we try to create a model of it. Or, for very small things that cannot be seen with the naked eye, we attempt to model them. Another important aspect is reasoning—asking why. This forms the foundation of theories. Why does something happen? Why is this the case? Delving into these questions and providing explanations is crucial. How can I explain it? What evidence can I present? Does it gain social acceptance, or how can I convey it socially? These are what I mean by scientific practices." (Leyla, Pre-interview)

Moreover, Teacher Leyla shared valuable teaching experiences related to scientific practices. She encouraged her students to observe the phases of the Moon and created scenarios, asking them to provide explanations. For example, she might say, "There's no life on the Moon. What would be necessary for life to exist there? Let's make some predictions." It can be concluded that Teacher Leyla integrates diverse scientific practices into her lessons. However, she does not explicitly teach these practices.

Table 4.18. Leyla's pre and post codes from the interviews on the SP of RFN.

	Pre-Codes	**Post-Codes**
SP	Data Discussion, Prediction Observation, Experimentation Modelling, Explanation Social certification	BRH Scientific activities Data, Prediction Modelling Discussion, Social certification, Reasoning
Teaching SP	Implementation of all SPs	Using BRH in science lessons Asking questions about SPs

After the intervention, Teacher Leyla explained SPs using Benzene Ring Heuristics (BRH). She listed the scientific practices as modeling, prediction, real-world, scientific activities, reasoning, discussion, and social certification. She clarified the analogy of BRH, which symbolizes six key SPs along with social ones. According to the teacher, these practices are interconnected and can be applied simultaneously in scientific work. Thus, the BRH is memorable and provides a framework for exploring scientific activities in class, such as observing data, analyzing it, or discussing its significance. By integrating these practices

into lessons, teachers can encourage students to reflect on their experiences and ask targeted questions to deepen understanding. Her perspective was expressed as:

> "When thinking of SPs, the BRH serves as a metaphor, symbolizing six key SPs: modelling, prediction, data, scientific activities, real world with reasoning, discussion, and social acceptance. These practices are interconnected and can be used simultaneously in scientific work… I believe the BRH is particularly memorable—it's not a complex shape. E.g.., in class, we could ask, which of these practices did we use today? Or, if a specific practice was employed, such as data analysis, we might ask, what does data provide us? Why do we engage in modelling? We can ask students both about which practices were used in connection to the BRH and about SPs, directing questions toward them to deepen understanding." (Leyla, post-interview)

It can be said that, following the intervention, Teacher Leyla gained a deeper understanding of scientific practices and explained the function of BRH more effectively. Additionally, she emphasized the necessity of explicitly teaching scientific practices in science lessons. She also proposed various questions that could be incorporated into science lessons to enhance student engagement and understanding.

Leyla's Perception of the Scientific Methods and Methodological Rules

Teacher Leyla perceived M as comprising two main types: manipulation with hypothesis testing and observational methods without hypothesis testing, prior to participating in the PD program (see Table 4.19). She also connected these methods to the development of scientific knowledge by forming, testing, and revising hypotheses. Additionally, she reflected on how she incorporates these methods in her classroom by prompting students with questions about research questions, hypotheses, predictions, and their observations rather than the scientific methods they use. She stated her views as:

> "When I think of M, starting with a hypothesis—formulating a hypothesis, presenting it, and testing it, which I often practice with my students. E.g., what is a hypothesis? It's our scientific idea that we want to test. We can conduct experiments and activities to test it. There are methods that don't involve a hypothesis, such as observation. These are SP that begin with observation or are based on modelling without testing a hypothesis… E.g., I might ask about the hypothesis: "What are they trying to test here? What are they investigating? What has been changed or not changed between the two images? What effect were they trying to observe?" (Leyla, post-interview)

It can be said that Teacher Leyla had a strong grasp of scientific methods; however, she could benefit from exploring additional types of scientific methodologies and enhancing her approach to teaching various scientific methods in science lessons.

Table 4.19. Leyla's pre- and post- codes from the interviews on the M of RFN.

	Pre-Codes	Post-Codes
M	Hypothesis testing Non-manipulation and not-hypothesis testing	Brandon's matrix Manipulation Non-manipulation Hypothesis testing Not- hypothesis testing
Teaching M	Doing experiments Making observations Asking questions about SPs	Using Brandon's matrix Giving examples from history of science Teaching diverse scientific methods explicitly

After participating in the PD program, teacher Leyla explained scientific practices using Brandon's matrix. She identified four types of approaches to scientific methods: manipulation, with hypothesis testing, or non-hypothesis testing, and non-manipulation, with hypothesis testing or non-hypothesis testing (see Table 4.19). She effectively described the functions of Brandon's matrix and provided examples from the history of science shared during the PD program. She presented her ideas as:

> "After learning about Brandon's Matrix, it immediately comes to my mind when thinking about M. It shows that scientific work can be conducted through four possible approaches… Science is not just about conducting experiments. E.g., we might have a hypothesis but be unable to manipulate variables, or we might have the ability to manipulate variables but not start with a hypothesis. Alternatively, we might lack both a hypothesis and an experiment, focusing instead on examining existing studies. All of these are valid forms of scientific work, and none is inherently superior to the others. Different methods are suitable for different situations." (Leyla, post-interview)

After the intervention, Teacher Leyla internalized the four approaches to scientific methods and offered suggestions for effectively teaching them. She recommended using Brandon's Matrix, incorporating examples from the history of science as presented in the PD program, developing real-life cases that utilize diverse scientific methods, and explicitly connecting these methods in her teaching.

Leyla's Perception of Scientific Knowledge

Teacher Leyla classified SK as hypotheses, theories, and laws before participating in the PD program. She described the functions of each and emphasized that there is a common misconception regarding the transformation of theories into laws. She also provided examples for each type of SK. She highlighted the tentative nature of science, noting that

scientific knowledge changes, is reassessed, and grows through discussions, critiques, and further testing. It can be said that Teacher Leyla had a good understanding of the SK categories of RFN before the intervention. She expressed her ideas as:

> "The trio of hypothesis, theory, and scientific law vividly comes to mind for me. We were often taught that theories, when proven, turn into laws. However, that's not accurate. Scientific laws represent phenomena in the real world—things we discover and attempt to explain. Theories, provide explanations for these phenomena, while hypotheses are ideas proposed for testing. …When I talk about scientific laws, for example, I want to emphasize this point because children don't always know this. … I can also say that SK evolves. It changes, grows, and develops over time as it is reassessed, enriched with new information, debated, and critically examined. … "When I was your age, there were nine planets. Now it's eight. Could this change again?" (Leyla, pre-interview)

Table 4.20. Leyla's pre- and post- codes from the interviews on the SK of RFN.

	Pre-Codes	**Post-Codes**
SK	Hypothesis Theories Laws The functions of theories and laws	TLM (Theories, laws, models) The functions of TLM Scientific understanding
Teaching SK	Teaching tentative nature of science Teaching cumulative development of SK Giving examples about development of SK	Providing examples of TLM Explaining functions of TLM

After the intervention, Teacher Leyla classified SK as theories, laws, and models. She explained the functions of TLM and made connections to the PD program. In the PD program, an analogy (a wall, with each brick symbolizing different kinds of SK) was used to show that there is no hierarchy among the various types of SK. Following the intervention, she also mentioned models as a type of SK and how all contribute to scientific understanding. She suggested providing examples of TLM and explaining the functions of TLM in the science lesson. She articulated her thoughts as follows:

> "When we talk about SK, it refers to knowledge developed based on scientific principles and aligned with the values of science. What comes to mind here is the trio of law, theory, and model. There is no hierarchical order among them. They come together like the bricks of a wall to form scientific knowledge. Over time, this knowledge can evolve with new explanations. They support one another in a transformative way. E.g., a phenomenon exists, and a law describes what it is, while a theory attempts to explain why it happens. Together, they create a unified strength. Using examples of existing scientific concepts that students are already familiar with is highly effective. We can talk about the existence of gravity or the gravitational pull between masses…. Scientific laws state that there is a gravitational force between two masses or discuss the force of gravity. When it comes to theory, I would explain that many scientists try to understand why or how this phenomenon occurs. We reason about it and seek logical explanations, which is what a theory does. Models, on the other hand, are forms of SK that express these ideas in a more concise way. I would emphasize these points and incorporate them into my lessons. (Leyla, post-interview)

Leyla's Perception of the Social-Institutional Aspects of Science

Teacher Leyla had a good understanding of the SI, and she emphasized the impact of social values, service to society, political decisions, and economic resources on science before joining the PD program. She noted that there are two directional relationships between these issues and science. Specifically, if a country has a strong economy, good relations with other countries, and values science, its priorities will often include scientific research. When discussing her teaching of SI, she explained that she generally addresses these issues verbally. She provided an example from the 8th-grade science topic of inheritance and how she mentions scientific ethos (e.g., cloning).

Table 4.21. Leyla's pre- and post- codes from the interviews on the SI of RFN.

	Pre-Codes	**Post-Codes**
SI	Social values Serving to society Political decisions Economic resources	Mutualistic relationship between science and society Society where SK produces Financial systems Political power structures Religion, race, gender, ideology Social values Scientific values Social dissemination Dynamic and complex nature of science
Teaching SI	Teaching scientific ethos with examples (e.g. cloning)	Teaching through keeping a report in the scientific work Teaching through investigating a report with peers Explaining SI dimensions (social values, financial system, scientific ethos, etc.) Teaching through watching documentaries Teaching through scientists' lives Teaching invitation of scientists to the school Teaching experiencing TÜBİTAK 4006 projects

Teacher Leyla, after the PD program, emphasized the mutualistic relationship between science and society. She also stated that science has a dynamic and complex nature due to that relationship. She focused on several SI categories, such as financial systems, political power structures, social values, and social dissemination. As keywords, religion, race, gender, and ideology were highlighted by Teacher Leyla. She articulated her thoughts as follows:

> "When thinking about science, it is definitely shaped within society and, in turn, influences society… the society's economic structure, political system, religion, race, and gender ideologies. Alongside these, there are scientific values, but also social values. There's also the aspect of how scientific knowledge is socially shared—how it is shared, what should be considered, and how it interacts within these systems of power. … It's a reciprocal relationship. While science is influenced by society, it also influences society. This two-way relationship reveals the dynamic and complex nature of science. This concept is highly applicable. … When discussing social values, we can explore the ideologies of the society in which science is created—how race, religion, and gender influence it; how suitable the social environment is for conducting scientific work; and how much support or criticism such work receives. Scientific values, on the other hand, pertain to conducting work ethically, prioritizing societal benefit, universality, and developing knowledge on an impartial and honest basis…. The political aspect also plays a role—for instance, the level of importance governments place on scientific studies, how much funding is allocated, and how frequently these issues are discussed in parliament. Economically, it's about the level of funding available, the budget allocated, and the mutual benefit scientific studies provide to the country. Social acceptance is another critical factor. Once scientific knowledge is created, its acceptance and dissemination must follow. How many reports are prepared, how frequently it is discussed at conferences, and the peer-review process in academic journals are all part of this process. Scientific knowledge shouldn't remain confined to an individual; it requires evaluation, critique, and, if beneficial, sharing with humanity. Professional activities are also crucial. How professionally a scientific study is conducted—adhering to ethical principles and maintaining scientific rigor—is part of this consideration. Evaluating and reviewing data and findings, and subjecting them to critical examination, are all necessary." (Leyla, post-interview)

Teacher Leyla advanced her teaching of SI after the PD program. For Leyla, teaching by maintaining a report in scientific work and exploring a report with peers was viewed as an effective method. She asserted that SI dimensions (social values, financial systems, scientific ethos, etc.) can be conveyed in the classroom. Other recommendations from the teacher included teaching through watching documentaries, showcasing the lives of scientists, inviting scientists to the school, and engaging in TÜBİTAK 4006 projects. She articulated her ideas as:

> "These topics can be addressed in lessons as they are inherently part of daily life. Documentaries can be shown, examples from the lives of scientists can be highlighted, and inviting scientists to schools could be beneficial. Students can explore these aspects of science more effectively through programs like TÜBİTAK 4006, where they can actively participate in projects and gain firsthand experience.... Whether a new discovery or ongoing research, relating it to these SI dimensions can be very effective. For example, having students create reports on their work and later peer-reviewing each other's work to transform it into a scientific format could be impactful. " (Leyla, post-interview)

4.1.2.5. Case 5 – Melisa's NOS Perception. Teacher Melisa entered the PD program with a strong foundation in the RFN framework, which she developed during her pre-service teacher education. While her initial perceptions of each category were robust, the PD program provided her the opportunity to further discuss and enhance her understanding of the sub-components. After the intervention, her comprehension advanced, as she offered richer examples and approached the concepts with a more holistic perspective.

Melisa's Perception of the Aims and Values of Science

Before participating in the PD program, Teacher Melisa emphasized the aims and values of science, which include understanding and explaining nature, ethical principles, and honesty (avoiding plagiarism while building on others' work), along with the development of SK (see Table 4.22). According to her, while these topics are often addressed verbally in class, she incorporates hands-on activities whenever possible. For instance, she designed a worksheet on cell theory to illustrate how scientists built upon each other's work, tracing developments from the invention of the first microscope to the establishment of cell theory. It can be said that Teacher Melisa makes some connections to AV in her lesson before the intervention. In her pre-interview, she stated:

> "The aims and values of science. This is a topic I frequently emphasize in my lessons. In what way? Particularly regarding science's aim to understand and explain nature—I focus on this extensively. Beyond that, when it comes to values, I talk about ethical principles, drawing from others' work without engaging in plagiarism, the evolving nature of knowledge, and having diverse perspectives. For example, in the context of cell theory, I prepared a worksheet that detailed the steps from the invention of the first microscope to the development of the cell theory. It explored what scientists did, what they stated, and how they influenced one another's work. When preparing activities, if there's a relevant point to address, I prefer not to overlook it." (Melisa, Pre-interview)

Table 4.22. Melisa's pre and post codes from the interviews on the AV of RFN.

	Pre-Codes	**Post-Codes**
AV	Understanding nature Explanation Ethical values Honesty Development of SK	Serving to humanity Understanding nature Explanation Accuracy Respecting environment, human and living things Decentralizing power Communalism Novelty
Teaching AV	Teaching tentative nature of science Teaching cumulative development of SK Using technological tools Giving examples from the history of science Discussing scientific methods	Teaching through materials Giving examples from the history of science Teaching cumulative development of SK Teaching AV through posters or materials

It was found that after the intervention, Teacher Melisa developed her perception focusing on AV with greater depth. She mentioned the following codes that serve humanity: understanding nature, explanation, accuracy, respect for the environment, humans, and

living things, decentralizing power, communalism, and novelty. She expresses her ideas for the AV of science as:

> "When considering the AV of science, I understand it as being shaped at its core by the goals of serving humanity and understanding the universe. It involves explanation explaining the environment, phenomena, and formations. While doing so, it emphasizes accuracy, respect for the environment, respect for people and living beings, and defining how our work should be shaped. For me, these AVs create a framework, with each aspect of the framework representing a unique principle. This includes being accurate and clear, adding new knowledge rather than merely repeating existing information, and ensuring mutual respect among those conducting the work. Additionally, it emphasizes respect for the environment and humanity, and it promotes relationships based on collective benefit rather than self-interest. This is the framework I envision when I think about the AV of science." (Melisa, Post-interview)

In her post-interview, Teacher Melisa reflected on integrating these aims and values into teaching through storytelling, lesson plans, and historical examples such as the development of the atomic model to illustrate the continuous pursuit of better explanations in science. Teacher Melisa highlighted the challenge of making these concepts more tangible and visible to students and suggested that scientific stories, visual materials, and classroom displays could help reinforce these ideas. While acknowledging challenges such as limited classroom resources and time, she recommended consistent visuals of scientific values to make these principles more accessible and memorable for students.

Melisa's Perception of the Scientific Practices

Teacher Melisa perceived SP as methods, which include observation and experimentation (see Table 4.23). She stressed the domain specificity of scientific methods, noting that different scientific fields employ distinct methods in her lessons. For instance, astronomy relies on observation, while biology focuses on experimentation. She aims to convey the nature of scientific fields in her lessons by inviting scientists to her classroom, thus referencing scientific practices. She elaborated on her thoughts as follows:

> "When I think of SP, I think of the work that scientists do, and the methods they use. Do they conduct experiments, make observations, or perform comparisons? Which methods do they use for which tasks… Do I talk about this in class? Yes, especially when I talk about how different methods and approaches are used in different scientific fields. E.g., in the first units, we use the sky to explain, and then we move on to biology. Do they follow the same method? For example, can a scientist conduct an experiment at a desk when studying the sky? If so, what kind of experiment would it be? Or what would they do, and how would they gather information? I discuss SPs with the students. I think it's important because the children... But of course, these discussions are more verbal and tend to follow a question-and-answer format…" (Melisa, Pre-interview)

It can be said that, before the intervention, Teacher Melisa confused scientific practice with scientific methods. She attempted to teach the nature of various scientific fields, assuming that each had its own distinct scientific method.

Table 4.23. Melisa's pre- and post- codes from the interviews on the SP of RFN.

	Pre-Codes	Post-Codes
SP	Scientific methods Experimentation Observation	BRH, Hands on activities, Real world, Explanation, Prediction, Modelling Experimentation, Data
Teaching SP	Teaching diverse scientific methods Domain specificity of scientific methods Increasing awareness about domains of science (social and positive science)	Questioning Storytelling Implementation of scientific practices Teachers' guidance for reasoning Discussing on scientific practices

After the intervention, Teacher Melisa's perception of scientific practices developed significantly. She made connections between hands-on learning and scientific practices, covering all components of BRH. These practices include predictions, data, explanation, experimentation, and real-life. She emphasized its cyclical nature, noting that there is no strict sequence for using SPs. She articulated her thoughts as follows:

> "In SP there is a focus on the hands-on aspect of science. Typically, a problem is identified, often derived from real life. The process involves working towards creating a meaningful, clear, and accurate explanation for the problem. Initially, we make predictions, which are then tested through experiments and observations. Throughout this process, we collect data and analyze it. All these steps fall under SP, serving as stages in producing meaningful, clear, and explicit knowledge. We question, test our predictions, make inferences, and so on. This process can be cyclical; you may return to a previous step or move to a different one. For me, it's not a strict hierarchy or linear sequence but rather a flexible flow. E.g., we might begin with a problem scenario like sugar dissolving in a pocket." (Melisa, pre-interview)

Additionally, Teacher Melisa's suggestions for teaching scientific practices have developed. She provided guidance and meaningful framing for engaging students in scientific practices. For her, students need opportunities to practice skills such as observation, data collection, and analysis, with support to refine their predictions and identify relevant variables. Teachers play a critical role in helping students recognize the importance of their observations and explanations, making each step of the scientific process feasible in the classroom. She shared her perspective in these words:

> "I often emphasize the importance of questions and guidance. A child might not see the sugar dissolving as a problem, so we need to frame it in a way that makes it meaningful for them. At this point, it's crucial to provide opportunities for practicing scientific skills. E.g., students need to observe, understand what observation entails, and determine what to look for—differences, similarities, or other factors. They also need to know whether and why to record their observations and understand the implications of doing so. Similarly, when working with data, students should recognize what constitutes data and how to derive meaning from it. … E.g., when forming predictions, students often approach the task too broadly. This leads to discussions about which variables to manipulate and which to control. I believe each step of scientific practice can be implemented in the classroom, but the teacher's ability to guide students effectively is crucial. Even asking students to explain the basis of their reasoning can make a significant difference, as they might not initially recognize the foundations of their explanations. Therefore, I think it's possible to incorporate each SP step by step into teaching." (Melisa, post-interview)

Melisa's Perception of the Scientific Methods and Methodological Rules

Teacher Melisa considered scientific methods to be a step-by-step scientific research methodology before participating in the PD program. She identified this process as encountering a problem, reviewing existing studies, conducting an experiment or observation, testing a hypothesis, and reaching a conclusion (see Table 4.24). As a teacher, she explains and discusses each step of the experimental setup, encourages her students to consider the type of experiment and hypotheses involved, and guides them in evaluating whether the results meet their expectations, as well as what to do if they don't. She stated her views as:

> " I think of M and their steps involve encountering a problem, discovering it, and feeling discomfort about it. Then, asking what solution can be applied, what resources we have, what we know, how we can approach it, and reviewing existing studies. Based on this, organizing a study that minimizes the margin of error with the method I determine. This could involve an experiment, an observation, or the environment I encounter, following these steps. I try to explain these to students. I can say I'm particularly fixated on experimental setups as a teacher. I often ask, 'If we were to conduct an experiment on this, what kind of experiment would it be? What steps would we follow? What would our hypothesis be? Would our hypothesis be proven correct or incorrect?' I aim to briefly explain each step to the students. Ultimately, we reach a result. Did this result meet our expectations? If not, what should we do? I believe I touch on these points briefly." (Melisa, pre-interview)

Teacher Melisa expressed that she had been confused about the distinction between scientific practices and methods prior to participating in the PD program. After the intervention, she explained scientific methods using Brandon's matrix, which encompasses four types of approaches, including whether or not hypothesis testing and manipulation occur. It can be claimed that the teacher's suggestion for teaching scientific methods did not change significantly. She recommended directing questions about each step of their experiment or observation and emphasized explaining the distinctions between manipulation and non-manipulation. She articulated her thoughts as follows:

> "At that point, I felt like everything was more interconnected. However, now when I think about methods and methodological theories, the first thing that comes to mind is the Brandon Matrix. It includes forming a hypothesis, testing or not testing it, and manipulation—changing variables or not. … Previously, I used to associate experiments, observations, and predictions with these concepts at this exact point, and my perception was more intertwined. But after the training sessions, now when I think of scientific methods, the matrix immediately comes to mind. In the matrix, hypothesis formation, manipulation, and variable changes are crucial components. This aspect aligns closely with scientific practices because conducting experiments or making observations provides opportunities to address these elements more thoroughly. … If we're talking about an experiment or an experimental setup in class, we must address an unchanging hypothesis and the variables. We need to discuss how to choose and change variables. … However, it's crucial to clearly explain the distinctions: when we form a hypothesis, how we test it, whether we manipulate variables, and the reference point for our observations. …" (Melisa, post-interview)

Table 4.24. Melisa's pre- and post- codes from the interviews on the M of RFN.

	Pre-Codes	**Post-Codes**
M	Step-by-step (the lock-step method) Stages of scientific research Experimentation Observation Constructing hypothesis Hypothesis testing Reconstructing	Brandon matrix Hypothesis testing Not-hypothesis testing Manipulation Non-manipulation
Teaching M	Directing questions about the steps of research Explaining experiment, hypothesis testing	Directing questions about scientific methods Explaining experiment, hypothesis testing, Explaining manipulation

Melisa's Perception of the Scientific Knowledge

Before the intervention, Teacher Melisa described scientific knowledge as the least falsifiable, most questionable, and most tested form of knowledge (see Table 4.25). For her, the types of scientific knowledge can either result from research or represent any step in the research process. She also referred to the tentative nature of scientific knowledge, emphasizing that it evolves through testing. She shared her perspective in these words:

> "SK is the least falsifiable knowledge formed based on all the resources and experiences we have regarding an existing topic. It is knowledge whose validity can be questioned and tested to determine whether it still provides accurate information or experience under different conditions. I think it has various types. Sometimes, it can be processing knowledge related to a method, explaining how something is done. Other times, it can directly represent knowledge of a result. … SK is continuously tested. Therefore, examining under what conditions and circumstances it leads us where, whether it can be falsified, or if it has open points, allows us to progress with it. … I think it grows by being constantly tested in different environments. It develops through the contributions of various people, with different perspectives and curiosity-driven inquiries." (Melisa, pre-interview)

Table 4.25. Melisa's pre and post codes from the interviews on the SK of RFN.

	Pre-Codes	Post-Codes
SK	The least falsifiable knowledge Questionable knowledge Tested knowledge Tentative nature of SK Developing through testing	Cumulative development of SK Universal knowledge Reliable knowledge Valid knowledge TLM (Theories, laws and models) Different functions of TLM Dissemination of SK
Teaching SK		Distinguishing different kinds of SK Providing examples in the contexts Reasoning

According to Teacher Melisa, SK arises from science's mission to understand and explain the environment, developing cumulatively over time. It is universal knowledge for humanity, valid and reliable for all societies and individuals. She explained three types of scientific knowledge: models, laws, and theories, each with distinct functions. However, she believes that the distinction between definitions (laws) and explanations (theories) remains a challenging concept for teaching. She emphasized that there is no hierarchical relationship among these types, and they serve different purposes. Scientific knowledge grows through sharing results rather than being stored in isolation. She explains her thoughts as follows:

> "SK emerges from the mission of science to understand and explain the environment, and it is something that accumulates and develops over time. It is universal knowledge for humanity, meant to be valid and reliable for every society, every individual, and everyone. During the training sessions, three different types of SK were discussed: models, laws, and theories. There was a lot of discussion about laws and theories, such as which is which. … there is no hierarchical relationship between the different types of knowledge, but each has a different mission. … laws define and theories explain. …The development of SK occurs with every study, and this means that each study must be conducted in line with scientific values and purposes." (Melisa, post-interview)

Teacher Melisa believed that teaching SK to children can be challenging. According to her, it's important to show the various types of scientific knowledge and explain their purposes in context, such as how a model is constructed, like the solar system model. This approach allows students to comprehend the different types of SK, as they may otherwise struggle to differentiate between them. Providing context and purpose helps clarify these distinctions. She stated her views as:

> "By doing and sharing. I think teaching SK is a bit challenging. For children, because everything they see in textbooks, and I say is considered SK. … Showing them that there are different types of SK, at the right time and with the right context, can help. … SK should be introduced by starting with questions like, "What is its mission, and how is it useful to us?" or we discussed atomic models and the solar system model... Why do we create these models? Why do we need them? I think different types of SK can be introduced through such discussions. Because when we explain them with reasoning, it becomes clearer that there are different types. Otherwise, for a child, what's written in the book is knowledge, that's knowledge, and that's knowledge—distinguishing between them is very difficult for them. We need to show them the difference in context." (Melisa, post-interview)

Melisa's Perception of the Social-Institutional Aspects of Science

Teacher Melisa referred to sharing studies with other scientists and society, publishing research, and conferences as social-institutional aspects of science. Additionally, politics, economy, government, journals, and some scientific institutions like TÜBİTAK are other key terms that the teacher emphasized regarding SI. She expressed her ideas as:

> "Sharing their work with one another, publishing it, attending conferences, and the connections between science and politics, economics, and government constitute what I consider the social aspect of science. This includes how science reaches the public and how it is communicated. The social dimension of science is both the way scientists share their work with each other and how they communicate it to those outside the scientific community. I address this topic, especially focusing on the economic aspect. I explain that conducting science requires funding and that scientists need financial support to carry out their research. I also discuss how governments decide which projects to support. E.g., TÜBİTAK is an institution we are closely connected with at our school. We follow activities and publications regularly, whether through Bilim Genç or its Instagram page. TÜBİTAK aims to promote scientific endeavors, and I emphasize how science can be guided and supported based on the political, economic, and strategic needs of governments." (Melisa, pre-interview)

In her teaching, she implements the SI by explaining financial systems and political power structures (such as the concepts of economy, funding, and governmental support). For instance, she mentions TÜBİTAK as a supporting institution for science in her teaching. She also states that she explains our national military defense resources as part of the SI implementation. She invites scientists to the school to demonstrate the relationship between science and society. She articulated her thoughts as follows:

> "For instance, I discuss how investments are currently being directed toward unmanned weapons and aerial vehicles due to our country's need to showcase military strength. Additionally, we invite scientists to our school so students can see that scientists aren't isolated in an ivory tower saying, 'We are doing science.' They need to share their work with the public and build relationships with society. In our lessons, when historical processes come up, we talk about how scientists have supported and built upon each other's work. I make a point to explain that academic publications and conferences are platforms where scientists stay informed about each other's research. … I also share my own experiences. If I attend similar academic events as part of my master's studies, I tell my students, 'I'm preparing for an event like this; researchers and scientists do this kind of work,' and I explain it to them. I think that's about it." (Melisa, pre-interview)

Table 4.26. Melisa's pre- and post- codes from the interviews on the SI of RFN.

	Pre-Codes	Post-Codes
SI	Dissemination of SK Publishing studies Conferences Politics Economy Government	Social organizations and interactions Social organizations' interactions with society Professional activities Designing projects Evaluation of studies Writing articles Sharing findings Reliability and validity of SK Financial systems Political power structures
Teaching SI	Explaining financial systems (economy, funding) Explaining political power structures (governmental support) Explaining our national military defense resources Invitation of scientists to the school	Teaching through small working groups Teaching through making posters Teaching through experiencing TÜBİTAK projects

After the PD program, Teacher Melisa began using terms from the RFN literature, such as financial systems, political power structures, social organizations and interactions, professional activities, social certification, and dissemination. She emphasized the dynamic interplay among social organizations and their interaction with broader societal structures. Furthermore, she identified and elaborated on several key components of the social-institutional system of science, such as project design, study evaluation, article writing, dissemination of findings, and ensuring the reliability and validity of scientific knowledge. For her, these processes not only foster collaboration but also safeguard the integrity and trustworthiness of scientific work. Additionally, she stressed the importance of science communication, underlining that public engagement with scientific information shapes how research is interpreted, valued, and integrated into everyday life. Melisa also reflected critically on the role of funding in steering scientific agendas and acknowledged the bidirectional relationship between financial resources and scientific progress. She noted that scientific research is inherently political, often influenced by or influencing decision-making at institutional and governmental levels. Importantly, she recognized that these social and institutional dimensions of science have historically been underrepresented in science education, though their visibility is slowly increasing particularly in response to global issues such as the COVID-19 pandemic or developments in space exploration. These reflections reveal a more comprehensive and critical understanding of how science operates within complex societal frameworks. She expressed her views as:

> "My favorite aspect of science is undoubtedly its SI dimensions, where science is deeply intertwined with humanity and other societal institutions. For me, this includes two main aspects: the relationships among scientific entities and the interactions between these entities and society, along with its various components. This involves professional activities such as writing project proposals, evaluating each other's work, writing articles, sharing findings, and attending conferences. These activities not only facilitate collaboration among scientists but also help ensure the validity and reliability of the knowledge they produce. At the same time, as I mentioned earlier, we are trying to understand our surroundings, to comprehend this universe. Scientists must communicate this understanding to society, making science communication an invaluable part of its social and institutional dimensions. How does it reach the public? How does the public interpret it? How do ordinary individuals perceive scientific research? These are the kinds of questions this dimension addresses. When we talk about society's components, financial systems inevitably come into play. I particularly enjoyed what one of my Korean students once wrote: 'Science needs money, and money needs science.' It perfectly summarizes the reciprocal relationship between funding and scientific progress. To conduct science, funding is essential, and to generate wealth, scientific knowledge and products are necessary. This idea has stayed with me. Another aspect is political power. Yesterday, for instance, we discussed the recent news about Alper going to space. Was it a politically orchestrated scenario? What messages were being conveyed? Science is so embedded in daily life that these discussions are inevitable. For me, it's an engaging and enjoyable component to discuss. However, I think it is one of the least emphasized dimensions in education. For instance, I feel that it's only recently begun to appear in textbooks, especially in the context of space exploration. Before that, perhaps the pandemic brought some of these issues to light, such as the financial resources required to produce vaccines and the decision-making mechanisms of countries. But even these are only slowly being reflected in our curricula." (Melisa, post-interview)

Teacher Melisa believes that the coverage of topics such as funding and societal aspects of science often relies on the teacher's knowledge and ability to explain them. Activities like group discussions and creating informative, engaging posters act as small-scale simulations of these dynamics. The teacher finds discussing these topics enjoyable, highlighting the contributions of organizations like TÜBİTAK. In the poster-making activity, she expects students to utilize reliable information and evaluate the study. She expressed her experiences as:

> "The extent to which these topics are covered often depends on the teacher's knowledge and ability to articulate them. Activities like group discussions, where students are asked to convince each other of a point, are small-scale models of this concept. Similarly, assignments like creating posters that must contain accurate information and be engaging for others are also small simulations of these dynamics. Discussing these aspects is immensely enjoyable. For example, TÜBİTAK has made significant contributions. We are currently in the middle of a project period at school, and I work closely with my students. When I ask them, 'What materials do we need?' they sometimes reply, 'Teacher, aren't we supposed to buy them ourselves?' This opens up discussions about funding, which I believe are very valuable to bring up in the classroom." (Melisa, post-interview)

4.1.2.6. Case 6 – Zeynep's NOS Perception. Teacher Zeynep's perception about NOS developed after participating in the PD program. The following section presents her developmental process, comparing pre- and postcodes and quotations for each RFN category.

Zeynep's Perception of the Aims and Values of Science

Before the intervention, Teacher Zeynep connected with the nature of scientific knowledge and scientific methods. She discussed the tentative nature of scientific knowledge, the development of scientific knowledge, and the construction and testing of hypotheses (see Table 4.27). Therefore, it can be said that she had a naïve understanding of the AV of science before participating in the PD program. She expressed her ideas as:

> "I recalled that there is no absolute truth in scientific knowledge. Scientific knowledge can change and evolve. The aim of science is to reach data, formulate hypotheses, and develop theories—these are the concepts that came to mind for me. I constantly emphasize this in my lessons. In fact, I often give an example: "Today, we say gravity pulls, but tomorrow, we might say the sky pushes." This highlights how things can change, and these are indeed points I address in my lessons." (Zeynep, pre-interview)

In her teaching, she emphasized the dynamic nature of scientific knowledge, often using examples to illustrate this point, such as stating that what is understood as gravity pulling today could be interpreted differently in the future. This demonstrated her focus on the subjective nature of science concerning teaching aims and values.

Table 4.27. Zeynep's pre- and post- codes from the interviews on the AV of RFN.

	Pre-Codes	**Post-Codes**
AV	Tentative nature of science Development of scientific knowledge Constructing and testing hypothesis	Teaching the reasons of learning of science Objectivity Serving to humanity Honesty Accuracy Ethical values
Teaching AV	Teaching tentative nature of science	By constructing and testing hypotheses

After participating in the PD program, Teacher Zeynep's perception of the aims and values of science improved. She discussed various principles essential to teaching science, emphasizing the importance of comprehending the reasons for learning science, the role of objectivity, serving humanity, upholding honesty, ensuring accuracy, and adhering to ethical values. These codes, she explained, are crucial for shaping scientific inquiry and education.

Although Teacher Zeynep highlighted a wide range of values associated with science, including the importance of these principles in fostering a deeper understanding of the subject, she provided relatively few concrete examples of how to effectively teach these values in her science lessons. While her theoretical understanding developed, there appears to be a gap in translating these ideals into specific classroom practices or teaching strategies that actively engage students with the core values of science.

Zeynep's Perception of the Scientific Practices

Teacher Zeynep views scientific practices as making scientific concepts concrete, conducting experiments, and making observations (see Table 4.28). She provides examples from her science lessons. For instance, instead of poking a balloon with a needle, when the students used several needles to poke the balloon, they observed that it didn't pop. For her, these hands-on activities enable children to better discover scientific concepts. She articulates her thoughts as follows:

> "Scientific practices and applications aim to solidify the knowledge we provide in the learning outcomes, making it tangible through experimentation. We carry out these activities in the laboratory during certain lessons or practical courses. For example, when we teach pressure in class, instead of poking a balloon with a needle, we observe that the balloon does not pop when we use several needles to poke it. I believe this is a scientific practice. Or, when we place a ship into water and cover the glass, we observe that the ship doesn't get wet. Showing this to the children can serve as an application for them to discover the existence of atmospheric pressure." (Zeynep, pre-interview)

Table 4.28. Zeynep's pre- and post- codes from the interviews on the SP of RFN

	Pre-Codes	**Post-Codes**
SP	Making scientific concept concreate Experimentation Observation Exploration Lab implementations	BRH Observation Classification Data Real world Modelling
Teaching SP	Conducting experiments Hands on activities	Making connection to real life Implementation of scientific practices Asking questions about scientific practices

After the intervention, Teacher Zeynep explained scientific practices utilizing Benzene Ring Heuristics (BRH). She listed some of its components as observation, classification, data, real-world applications, and modeling (see Table 4.28). According to

Teacher Zeynep, she had already been using scientific practices unconsciously prior to the intervention. It was noted that Teacher Zeynep did not focus on social practices such as representation, reasoning, or discourse. Her suggestions for teaching scientific practices are provided below:

> "There are experiments, observations, and classification… There was a benzene ring model. In the benzene ring, students collect data, observe related problems from daily life, create models, and later… I can integrate this into my lessons as well. I even mentioned that I was unconsciously integrating scientific practices. The reason is that, by saying science is part of life itself, we can relate every topic to something from daily life. By relating it like this, for example, opening a jar could be integrated with a scientific practice. 'How can I open this?' This is an observation. They can collect data related to it, ideas can be gathered, and they can draw a model. They can sketch expansion and contraction as a model. Finally, they can classify the processes involved. All of these are part of scientific practices." (Zeynep, pre-interview)

Zeynep's Perception of Scientific Methods and Methodological Rules

Teacher Zeynep explained scientific methods as gathering data, experimentation, and hypothesis testing (see Table 4.29). She shared her experiences from a science project in which they developed a cream and conducted an experiment on worms to test its effectiveness. She emphasized that research methods, which help reach scientific knowledge, are central to her lessons. She also noted that conducting experiments is a fundamental skill. She explained her ideas as:

> "M... This could be data collection, for example. There was something last year... I had a TÜBİTAK project. In this project, we developed a cream, and to investigate whether the cream was really effective, we needed to collect data. We conducted an experiment on worms. We had 6 worms. We cut the tails of all 6 worms, applied the cream to 3 of them, and did not apply it to the other 3. Later, we observed the difference in the growth of their tails. This could be considered a M. … Research methods, everything that helps us reach SK, is a method for me. I definitely emphasize M in my lessons. Especially, as you probably know, the new form of questions is more focused on problems and experiments, so we often have to emphasize things like how to learn the existence of something, how to compare things, or how to test them." (Zeynep, pre-interview)

Table 4.29. Zeynep's pre- and post- codes from the interviews on the M of RFN.

	Pre-Codes	**Post-Codes**
M	Gathering data Experimentation Hypothesis testing	Brandon matrix Manipulation with hypothesis testing Non-manipulation without hypothesis testing
Teaching M	Conducting experiments Teaching hypothesis testing	Using Brandon matrix Teaching hypothesis testing Teaching variables Asking questions about different methods

Teacher Zeynep made a connection to the Brandon matrix but identified only two types of scientific approaches: manipulation with hypothesis testing and non-manipulation without hypothesis testing (see Table 4.29). It can be said that Teacher Zeynep's awareness increased after participating in the PD program. She provided examples of the two kinds of scientific methods from the training. She suggested that the Brandon matrix could be used as a resource for teaching diverse scientific approaches. Additionally, she recommended teaching hypothesis testing and variables and inquired whether there could be other methods for teaching scientific methods in science lessons. She states her views as:

> "I remember the Brandon Matrix. In Brandon's Matrix, there were experiments tested with hypotheses and those that were not tested with hypotheses but were based only on observation. E.g., when classifying living organisms, we couldn't identify any variables. We didn't have a dependent or independent variable. We were classifying them based on their lifestyles, types of nutrition, or their interactions with each other. In this context, there was information on how hypotheses can be tested. If that's the case, we can explain this table to the students. We can teach them what a hypothesis is and how a hypothesis can be tested.. After discussing dependent variables, independent variables, and control variables, we can always ask if these are necessary, and whether scientific research can be done, or a hypothesis can be tested without them. Through observation, we can conclude that it is indeed possible." (Zeynep, post-interview)

Zeynep's Perception of the Scientific Knowledge

Before the intervention, teacher Zeynep viewed SK as proven knowledge. She emphasized that SK has a tentative nature; however, she could not identify any types of it. She thought that she did not reference SK in her lesson. She expressed her ideas as:

> "SK is a knowledge whose accuracy is concreted with data, proven, and still true… No matter how much it is verified, it can change and develop at any moment. I know that there are types. I know the types of scientific knowledge, but since you ask me this, my mind is going to the classes at such a university right now and I realize I have forgotten…. There is no such an objective at the levels I entered. I don't remember ever talking to my students about SK." (Zeynep, pre-interview)

Table 4.30. Zeynep's pre and post codes from the interviews on the SK of RFN.

	Pre-Codes	**Post-Codes**
SK	Proven knowledge Tentative nature of SK	TLM (theories, laws and models) No hierarchy among them
Teaching SK		Teaching development of SK Asking questions about different types of SK Emphasizing reliability and validity of SK

Teacher Zeynep listed different kinds of SK as theories, laws, and models, referring to the wall model in the training. She admitted that she still does not clearly distinguish between the functions of theories and laws and can have difficulty providing examples of them. However, she noted that she is aware there is no hierarchy among them. She suggested teaching different kinds of SK by comparing them, asking questions about different types of SK, and emphasizing the reliability and validity of SK through the role of repetition in experiments and changing environmental conditions. She articulated her thoughts as follows:

> "SK, theory, law, model, there was a brick. It was something that all of them were intertwined. … In fact, I think I need to do more reading and research on this subject. I don't think I could convey it to the class in such a meaningful way. Because I couldn't distinguish law from theory very well in my own student life either. We just learned that their hierarchy was actually hierarchies that complemented each other, that they were not superior to each other, and that they only created each other. And we also told the students about these... We asked them to compare them. We got their ideas with the question-answer method and about the relevant subject... E.g. Let's say the atomic model. We asked them to draw their models of the atomic model... We also asked questions like how models are formed in their own minds. How does SK develop? …" (Zeynep, post-interview)

Zeynep's Perception of the Social-Institutional Aspects of Science

Teacher Zeynep reflected that she had not heard the concept of SI before. As a prediction, she stated that the social aspect of science refers to using scientific knowledge in societal contexts, while the institutional aspect of science pertains to TÜBİTAK and research and development studies. In her implementation, Teacher Zeynep mentioned that she teaches TÜBİTAK and TEKNOFEST to her students during the project-making process. This indicates that while her initial understanding was limited, she was already engaging with elements of the SI dimension in practice, albeit without explicit conceptual awareness. She explained her experiences as follows:

> "The SI... I can't quite grasp what it means. When I think of the SI is perhaps using scientific knowledge in social contexts, but... I'm still not sure. As for institutional aspects, what immediately comes to mind is TÜBİTAK. Something like R&D projects. ... We explained what TÜBİTAK is, the steps involved, how we need to identify a problem, and how to address it using the 5W1H method when creating a project. We shared a Google Form to gather students' ideas. Some of their suggestions were really good, while others were quite utopian. Based on the ideas we received, we continued to work on our projects in collaboration with different subject areas." (Zeynep, pre-interview)

Table 4.31. Zeynep's pre- and post- codes from the interviews on the SI of RFN.

	Pre-Codes	Post-Codes
SI	Usage of scientific knowledge in the social area TÜBİTAK Research and development studies	Social certification and dissemination Reliability of scientific knowledge Ways to reach scientific knowledge TÜBİTAK, TUA, TEKNOFEST (social organizations)
Teaching SI	Mentioning about TÜBİTAK and TEKNOFEST Teaching project making process	Talking about social organizations (e.g. TUA)

After the PD program, Teacher Zeynep's perceptions of SI did not show significant change. She mentioned several keywords related to SI, including social certification and dissemination, reliability of scientific knowledge, methods to access scientific knowledge, social organizations (e.g., TÜBİTAK, TUA, and TEKNOFEST), and social values. She articulated her thoughts as follows:

> "The SI involves the acceptance and dissemination of SK. E.g., is what we identify as SK always correct? How do we reach accurate knowledge? Or how is SK disseminated? Institutions like TÜBİTAK or TUA (the Turkish Space Agency), which we frequently discuss with students these days, play a role in the social dissemination of science. As for the institutional aspects, these include entities like TÜBİTAK, TUA, or even TEKNOFEST. All of these are examples of how science and SK are institutionalized and disseminated in tangible ways to benefit humanity. It's essentially the institutionalization of science and its applications." (Zeynep, post-interview)

4.1.2.7. Summary of the Individual Interview of Cases. Aylin's professional development journey reveals significant growth in her understanding of the NOS. Before participating in the PD program, her perception of the aims and values of science, scientific methods, scientific practices, and the social-institutional aspects was somewhat limited, often focusing on basic and practical classroom applications. She emphasized concepts like advancing humanity and teaching cumulative scientific knowledge, but lacked a broader perspective on ethical considerations, interdisciplinarity, and the interconnectedness of scientific elements. After the PD program, Aylin's understanding expanded considerably. She began to integrate ethical values, objectivity, and historical examples into her teaching. Her perception of SP evolved to highlight its iterative and collaborative nature, emphasizing the holistic integration of experimentation, observation, and modeling. Additionally, her understanding of M matured to recognize diverse approaches across disciplines, from hypothesis testing to observation-based studies. Lastly, Aylin demonstrated a deeper comprehension of the SI

aspects of science, acknowledging the roles of dissemination, financial systems, and political structures, and suggesting ways to incorporate these aspects into teaching through real-world examples and discussions. This transformation underscores the impact of the PD program in enhancing her ability to foster a nuanced and comprehensive understanding of science among her students.

Before participating in the PD program, Beren's understanding of the AV, as well as SP, M, and SI, was relatively basic, primarily focused on foundational knowledge and practical classroom applications. She emphasized issues related to the validation of scientific knowledge and teaching step-by-step methods, but her perspective on interdisciplinary approaches and the ethical dimensions of science was limited. After the PD program, Beren's perception evolved significantly. She began to recognize the importance of ethical values, collaboration, and the iterative nature of scientific practices. Her approach to teaching scientific methods became more diverse, incorporating observation-based studies and emphasizing the interconnectedness of scientific processes. Additionally, her understanding of the SI expanded to include the roles of political, financial, and social structures, which she actively integrated into her teaching strategies through discussions and real-world examples. This shift highlights the transformative impact of the PD program in enriching her NOS teaching framework.

When analyzing the different dimensions of the NOS, Deniz's professional development highlights a significant evolution in her understanding. Before participating in the PD program, her perceptions were somewhat narrow and practical, emphasizing concepts like serving humanity, sustainability, and basic hands-on applications. Her understanding of SK, SP, and M was foundational, prioritizing step-by-step approaches and basic experimental demonstrations. While she acknowledged the importance of teaching NOS, she lacked specific examples and held misconceptions, such as theories evolving into laws. After the PD program, Deniz's perspective broadened, incorporating a wider range of themes and deeper insights. She demonstrated an improved understanding of SP by emphasizing holistic approaches, interconnectedness, and diverse strategies such as modeling and classification. Her grasp of scientific methods evolved with the use of frameworks like Brown's Matrix, enabling her to teach various methodological approaches. Additionally, her understanding of SK deepened as she explored the interconnected roles of theories, laws, and models. In

social-institutional aspects, Deniz began incorporating topics like political power structures, financial systems, and social organizations into her teaching, utilizing real-world examples and interactive methods such as discussions and field trips. This development underscores the positive impact of the PD program on transforming her NOS teaching practices and enhancing her ability to convey complex scientific concepts effectively.

When examining the dimensions of the NOS, Leyla demonstrated a strong foundational understanding before her participation in the PD program, with notable growth afterward. Before the intervention, she already had a solid grasp of the AV of science, emphasizing epistemic, cognitive, social, and ethical aspects. She encouraged students to critically engage with scientific contributions, cultural influences, and ethical dilemmas. Similarly, Leyla showed a strong understanding of SP, linking them to real-world applications and utilizing engaging teaching methods like observation and prediction. However, her approach to teaching SP and M lacked explicit structure and diversity. After the PD program, Leyla significantly expanded her NOS framework. She incorporated more nuanced concepts such as universality, objectivity, and ethical principles into her understanding of the aims and values of science, while emphasizing their importance in fostering critical thinking. Her perception of scientific practices deepened, and she effectively applied the BRH to teach interconnected practices like modeling and discussion. Leyla also internalized diverse scientific methods through Brandon's Matrix and proposed strategies such as using historical examples and real-life scenarios to teach these concepts effectively. Her understanding of SK evolved with the introduction of models as a key category, alongside theories and laws, and she adopted the "wall" analogy to explain the non-hierarchical relationship among them. Regarding the SI of science, Leyla's insights expanded to include the dynamic interplay between science and society, emphasizing financial systems, political structures, and social values. She suggested innovative teaching methods such as using documentaries, discussing scientists' lives, and engaging students in TÜBİTAK projects. Overall, the PD program greatly enriched Leyla's NOS perspectives and strengthened her ability to teach these dimensions in meaningful and engaging ways.

Before participating in the PD program, Melisa demonstrated a foundational understanding of the NOS, albeit with some limitations. She viewed the AV of science as centered on understanding and explaining nature, adhering to ethical principles, ensuring

honesty, and avoiding plagiarism. In her lessons, she occasionally connected these values through activities such as tracing the development of cell theory, but these efforts lacked depth. Melisa also confused SP with M, primarily associating them with observation and experimentation. She believed that different fields of science employed distinct methods, a notion she attempted to convey by inviting scientists to her classroom. Concerning M, she perceived them as a linear problem-solving process, while her understanding of scientific knowledge focused on its tentative nature and its classification into models, laws, and theories. In terms of the social-institutional aspects, she highlighted the roles of politics, the economy, and institutions like TÜBİTAK, but provided limited examples and context in her teaching. After the PD program, Melisa's understanding and teaching of NOS improved significantly. She broadened her perception of the aims and values of science, emphasizing concepts such as serving humanity, decentralizing power, and respecting the environment. She integrated these values into her lessons through storytelling, visual aids, and historical examples to make abstract ideas more accessible. Her understanding of SP evolved with the BRH, recognizing the interconnected and cyclical nature of these practices; she emphasized hands-on learning and guidance to engage students effectively. With Brandon's Matrix, Melisa gained a nuanced understanding of M, distinguishing between hypothesis testing, manipulation, and non-manipulation, although her teaching suggestions remained consistent. She refined her perception of SK, emphasizing the complementary roles of theories, laws, and models without hierarchy and proposing the use of real-life examples to help students grasp their purposes. In the SI dimension, Melisa adopted a more comprehensive approach, incorporating RFN concepts such as social certification and dissemination. She emphasized the reciprocal relationship between science and society, addressing funding, political structures, and public communication through activities like poster-making and discussions, making science more dynamic and relevant to students.

Before participating in the PD program, Zeynep had a limited understanding of the aims and values of science, mainly connecting them to the nature of scientific knowledge and methods. She emphasized the evolving and tentative nature of scientific knowledge, often using examples like gravity to illustrate its dynamic character. However, her understanding of core scientific values, such as objectivity, honesty, and ethical practices, was somewhat naive, and she lacked a comprehensive framework for integrating these values into her teaching. Zeynep viewed scientific practices as hands-on activities that made

abstract concepts concrete, such as using multiple needles to poke a balloon to understand how pressure works. In terms of scientific methods, she focused on data collection, experimentation, and hypothesis testing, but did not fully grasp the diversity of approaches. Her perception of scientific knowledge was somewhat basic, and she did not differentiate between types of scientific knowledge or their functions. Regarding the social-institutional aspects of science, she had limited awareness, understanding them mainly in terms of applying scientific knowledge in society and referring to institutions like TÜBİTAK. After the PD program, Zeynep's perception of the aims and values of science significantly expanded. She now recognized a broader range of values, including objectivity, serving humanity, and adhering to ethical principles, although she struggled to fully translate these into practical teaching strategies. Her understanding of scientific practices became more sophisticated, as she began incorporating the BRH, recognizing the cyclical nature of scientific practices and the importance of activities such as observation, classification, and modeling. Her awareness of different scientific methods increased after the program, and she began to use the Brandon Matrix to identify various approaches, suggesting methods like hypothesis testing and discussing variables in her lessons. Zeynep's understanding of scientific knowledge also deepened; she now acknowledged the distinct roles of theories, laws, and models, though she still struggled to clearly explain their functions. In terms of social-institutional aspects, while her perception did not drastically change, she now included concepts like social certification, the reliability of scientific knowledge, and the roles of organizations like TÜBİTAK, TUA, and TEKNOFEST, incorporating them more explicitly in her teaching.

Table 4.32. Codes obtained from individual interviews for each ca

Cases/ Categories	Aylin	Beren	Deniz	Leyla	
AV-Pre	Validation of SK Explanation Advancement of humanity Questionability	Ethical values Honesty Serving to humanity Development of SK Universality	Sustainability Serving to humanity Development of SK Certainty	Epistemic, cognitive and social values Ethical values Universality Serving to humanity Respecting environment, human and living thing Historical and political context	
AV-Post	Ethical values Honesty Questionability Objectivity Decentralized power	Ethical and moral values Characteristics of scientists Empirical adequacy Dissemination of SK Universality	Epistemic, cognitive and social values Teaching the reasons of learning of science Serving to humanity Linking technological progress with SK Understanding nature	Universality Honesty Objectivity Decentralizing power Serving to humanity Accuracy Ethical values	

Table 4.32. Codes obtained from individual interviews for each case.

Cases/ Categories	Aylin	Beren	Deniz	Leyla	
SP-Pre	Scientific processes Scientific methods Research methods Reporting findings	Experimentation Observation	Hands on application Observation Experimentation	Data Discussion, Prediction Observation, Experimentation Modelling, Explanation Social certification	S I C
SP-Post	BRH Experimentation Observation Classification Modelling Discussion Real world Explanation	Gathering data Observation Modelling Prediction Experimentation Scientific activities Inferences Real world	BRH Real world Model Data Classification Observation Experimentation	BRH Scientific activities Data Prediction Modelling Discussion Social certification Reasoning	I I I I I N I I
M-Pre	Domain specificity of M (for different branches) Step-by-step method Identifying a problem Conducting theoretical research Forming a hypothesis Hypothesis testing	Observation Experimentation Hypothesis testing Solving problem	Step-by-step (the lock-step method) Constructing hypothesis Testing hypothesis Re-constructing hypothesis	Hypothesis testing Non-manipulation and not-hypothesis testing	S I S n I C C I I

Table 4.32. Codes obtained from individual interviews for each case.

Cases/ Categories	Aylin	Beren	Deniz	Leyla
M-Post	Brandon Matrix Manipulation, Hypothesis testing Observation	Brandon matrix Manipulation Non-manipulation Hypothesis testing Not-hypothesis testing	Brandon matrix Manipulation Non-manipulation Hypothesis testing Not- hypothesis testing	Brandon's matrix Manipulation Non-manipulation Hypothesis testing Not- hypothesis testing
SK-Pre	Falsifiability Verifiability Hypothesis testing Empirical evidence Curiosity and questioning Skepticism and critical thinking	Tentative nature of SK Cumulative development of SK Quantitative knowledge Qualitative knowledge	Proven knowledge Supported knowledge Tentative nature of SK Cumulative development of SK	Hypothesis Theories Laws The functions of theories and laws
SK-Post	TLM Differentiation between theories and laws Cumulative development of SK Universal language Scientific understanding	TLM (Theories, laws and models) Differences among TLM	TLM Differences among TLM Tentative nature of SK Cumulative development of SK	TLM The functions of TLM Scientific understanding

Table 4.32. Codes obtained from individual interviews for each case.

Cases/ Categories	Aylin	Beren	Deniz	Leyla
SI-Pre	Humanity Bureaucracy	Social conditions that affect scientists' studies	Society The viewpoints of society toward science Belief system Social certification and dissemination	Social values Serving to society Political decisions Economic resources
SI-Post	Social dissemination (sharing knowledge with society and scientists) Financial systems (etc. materials) Political power structures Social organizations	Social values (serving to humanity) Social dissemination (publication) Collaboration among scientists Financial systems Social organizations (e.g. NASA, TÜBİTAK, research institutions, institute of science in universities) The impact of government and religion Political power structures Social values Professional activities	Social values (e.g. serving to humanity, no harm, respect to each other, respect to environment) Social organizations (CERN, TÜBİTAK) Social certification (accepting or rejecting SK, investigation of SK with experts) Political power structures (Gender inequality) Financial systems Articles Organizing seminars Sharing knowledge (dissemination)	Mutualistic relationship between science and society Society where SK produces Financial systems Political power structures Religion, race, gender, ideology Social values Scientific values Social dissemination Dynamic and complex nature of science

4.2. Results of the Second Main Research Question

The second main research question is “RQ2. How do teachers translate their NOS understanding into instructional practices after participating in the RFN-based online reflective and collaborative PD program?” This research question consists of two sub-research questions referring to teachers’ teaching planning (RQ 2.1) and their teaching practice (RQ 2.2). For each sub-research question, results are presented separately for each case, and then comparisons are made among the cases. Finally, the sub-research questions were combined to answer the second main research question.

4.2.1. Results of Incorporating NOS Activities into Their Lesson Plans

During the training, teachers gained theoretical knowledge about different RFN categories, and each week they developed lesson plans as groups. In this section, the results of the first sub-research question of the second main question are presented. It is “RQ2.1. How do science teachers integrate NOS-based activities into their lesson planning after participating in the RFN-based online reflective and collaborative PD program?” For this research question, four data sources are analyzed: individual interviews, lesson plans, teacher journals, and group discussions during the lesson plan development session. The results of each data source are presented for each case separately below, and finally, a comparison of cases is reported.

For the “individual interview” data source, teachers are asked the questions, “What do you think how this PD program has developed you? How do you plan to integrate NOS into your lessons from now on? What do you think about the effects of the PD program on your lesson plans?” to gather information about the effects of PD on their lesson planning. The answers from each case are analyzed, and related codes and quotations are reported for each case separately.

For the “lesson plan” data source, the Lesson Plan Assessment Rubric scores are reported separately for each case. Teachers’ lesson plans are analyzed by considering the thirteen items in the Lesson Plan Assessment Rubric, such as “The lesson plan explicitly states the RFN learning objectives” and “The activity in integrating of RFN category to the

scientific topic is appropriate." After analyzing seven lesson plans for each case, each lesson plan is summarized, and a summary table is prepared for every case.

For the "teacher journal" data source, teachers responded to the questions of "(1) How did you integrate the NOS category into your lesson plans? Why did you choose this instructional practice, strategy, or method in your lesson plan?" and "(2) Did you have difficulty integrating the NOS category into your lesson plans? At what point did you face challenges?" in their weekly journal. Based on seven weeks of reflections, their transformation of NOS understanding into lesson planning is presented for each case along with relevant quotations.

For the "group discussion" data source, teachers' group discussions during lesson planning sessions are analyzed. Each audio recording is transcribed, and the transcriptions are analyzed based on the themes: (1) selection of NOS objective, (2) integration of NOS into the lesson plan, (3) determining activity, (4) determining instructional strategies, (5) NOS evaluation, and (6) leading group discussion. After analyzing each lesson plan, teachers' progression in integrating NOS issues into lesson plans is determined. Related quotations are provided. The subsequent report presents the findings of each case, including four data sources.

4.2.1.1. Case 1 – Aylin's Teaching Planning. In this session, data sources such as individual interviews, lesson plans, teacher journals, and group discussions are analyzed to investigate how teacher Aylin incorporates NOS activities into her lesson plans while participating in the online reflective collaborative professional development program structured by the RFN framework. Teacher Aylin teaches 5th, 6th, and 7th grades at her school. Thus, she collaborates with other teachers during the lesson plan development sessions.

Aylin's Individual Interview

Teacher Aylin is asked what she thinks about the effect of online reflective collaborative PD on her lesson planning. She highlights the impact of the PD program on her teaching approach and professional development. After participating in the PD program, she paid attention to making connections to NOS issues in her lessons. She believes that

questions related to NOS issues, connecting to real life, and providing examples from the history of science have become fundamental to her lessons. The shift from asking factual questions to encouraging deeper inquiry demonstrates a meaningful integration of NOS into her lessons. By fostering curiosity and critical thinking, the teacher has created a classroom environment where students actively engage with scientific concepts. Through this, she benefits from the presentations and example lesson plans from the PD. She expresses her ideas as:

> "… This approach has become ingrained in us, and I want to continue using the NOS in my teaching. I have also downloaded your presentations and example lesson plans, and whenever something comes to mind, I open them and review them… This method helps students understand concepts much better. … Even when I am not consciously thinking about scientific practices or knowledge, the questions we have formulated together keep coming to my mind. I naturally incorporate them into my teaching…. I automatically think about what questions to ask. I have learned to ask, 'How was this discovered?', 'How does this work?', and 'How can this happen?'. I even apply this approach in my own PD. I recently had an interview with a school. During my sample lesson, I used the NOS to explain specific heat. Instead of teaching classically, I integrated examples from the NOS, and they were quite surprised… I said, 'This is directly related to the NOS and SP.' At that moment, I felt like I had earned an extra point. That's why I truly believe I have grown professionally. (Aylin, post-interview)

It can be said that Teacher Aylin does not prepare daily lesson plans for her science lessons in written form, but she thinks about the flow of the lesson, questions, and examples prior to the lesson. After participating in the PD program, she always considers how to integrate NOS into her lessons. Additionally, her personal anecdote about using NOS in a job interview further reinforces the program's professional impact, demonstrating how these strategies extend beyond the classroom. Overall, her response convincingly conveys how the PD program has shaped her teaching practices and underscores her commitment to sustaining these methods in the future

Aylin's Lesson Plans

Aylin worked as a group with all the teachers during the lesson planning sessions. Her and her group members' scores for each lesson plan, gathered from the Lesson Plan Assessment Rubric, are presented in Table 4.33. The lesson plans are evaluated and summarized based on the items in the Lesson Plan Assessment Rubric.

Table 4.33. Aylin's lesson score for each lesson plan.

Group members with Aylin	**Ley.**	**Zey.**	**Den.**	**Den.**	**Mel.**	**Ber.**	**Ley.**
Item of assessment rubric/LP	LP1 (AV)	LP2 (M)	LP3 (SP)	LP4 (SK)	LP5 (SI)	LP 6 (MIX1)	LP 7 (MIX2)
1. The lesson plan explicitly states MoE learning objectives.	3	3	3	3	2	3	3
2. The lesson plan explicitly states RFN learning objectives.	2	2	3	3	3	3	3
3. All stated RFN objectives are covered in the lesson plan/ all taught RFN objectives are explicitly listed in the RFN objectives list.	1	2	2	3	2	2	2
4. The lesson plan clearly describes prior knowledge of the students.	3	3	3	3	3	3	3
5. The lesson plan clearly describes procedures.	3	2	3	3	3	3	2
6. The activity in integrating of RFN category to the scientific topic is appropriate.	3	3	3	3	3	3	3
7. The RFN category is referred at least two parts of the lesson plan.	1	3	1	3	3	3	2
8. The lesson plan includes variety of resources/materials integrating technology.	3	3	3	3	3	3	3
9. The lesson plan promotes active engagement of students.	3	3	3	2	2	2	2
10. The lesson plan includes a variety of instructional techniques.	3	3	3	3	2	3	2
11. The lesson plan includes appropriate assessment methods.	3	2	3	3	2	3	2
12. RFN objectives are assessed during the assessment part of the lesson.	3	2	3	3	3	3	1
13. The lesson plan is instructionally appropriate in terms of time management.	3	3	3	3	3	3	3
Total Score:	34	34	36	38	34	37	31

The lesson plan for the AV category of RFN is completed with teacher Leyla for 7th grade students. The topic is Conservation of Energy. The MoE objective is "Students will be able to conclude that energy is conserved based on the transformation between kinetic and potential energy types." The RFN objective is "Students will be able to take opposing ideas seriously and try to refute them by presenting scientific evidence." In the assessment part of the lesson plan, there are questions that refer to critical thinking, accuracy, and experimental adequacy, such as "What kind of reasons did you provide to justify your

conclusions? (Critical Thinking)", "How did you evaluate the accuracy of the explanations presented by other groups? (Principle of Accuracy)", and "Do you think the claims presented by the groups were based on sufficient, relevant, and reasonable data? (Experimental Adequacy)?" Thus, it can be said that the lesson plan does not explicitly state the RFN learning objectives. The lesson plan clearly describes the students' prior knowledge and procedures. The activity integrating the RFN category with the scientific topic is appropriate, but it only focuses on NOS issues in the assessment part of the lesson plan. Thus, NOS is perceived separately from the science topic. The lesson plan includes a variety of resources and materials that integrate technology and employ different instructional techniques. It promotes active engagement among students and includes appropriate assessment methods. There is a group activity where students draw graphics of conservation of energy. Finally, it is instructionally appropriate in terms of time management.

For the lesson plan M category of RFN, the topic is Force and Movement for 6th grade students. This lesson plan is designed in collaboration with Teacher Zeynep. The MoE objective is clearly stated: "Students will be able to represent the relationship between distance, time, and speed on a graph." NOS objectives focus on manipulation and hypothesis testing. The NOS objectives are: "Students formulate a testable hypothesis" and "Students identify the variables to be used in their activities." Additionally, non-experimental methods are discussed in the elaboration section, though they are not explicitly listed as learning objectives. The procedures of the lesson plan are not very clear, as the implementation of NOS emphases is not explicitly stated. While the activity sheet includes NOS-related questions, it is unclear how the teacher integrated these topics into the lesson and provided the necessary context. The activity sheet is well-designed, incorporating a real-life problem to establish context. However, the lesson plan includes too many variable-related questions at once, leading to a lack of coherence and flow between the questions. Despite this, the plan provides an extensive focus on scientific methods. Various teaching strategies are employed, and efforts are made to keep students actively engaged. The lesson plan includes appropriate assessment methods and time management.

In the lesson planning for the SP category of RFN, Teacher Aylin collaborated with Teacher Deniz on the issue of friction force for 7th-grade students. The chosen MoE objective is "Students will be able design a vehicle to reduce the effect of air or water

resistance.” NOS objectives include both the aims and values of science as well as scientific practices. The selected objectives are: "Students propose suggestions regarding the purposes of scientific studies.", "Students provide reasons to justify claims.", "Students base claims on sufficient, relevant, and reasonable data.", "Students respect all ideas as long as they are evidence-based, regardless of their source.", "Students relate the scientific practices they use during activities to the Benzene Ring Heuristics Analogy." and "Students design scientific activities through observation." However, some objectives related to the aims and values of science were not explicitly emphasized during the lesson, and scientific practices were only addressed in the assessment section of the lesson plan. It is also necessary to explain how NOS issues are connected to the lesson. The lesson plan follows the 5E model effectively, ensuring a well-structured progression. The lesson plan clearly describes the prior knowledge of the students and the procedures. The students design a parachute, considering air resistance, to prevent the eggs from breaking when dropped from the 5th floor. They are actively engaged and encouraged to work collaboratively in groups. The lesson plan includes a variety of resources and materials that integrate technology. The assessment section contains questions related to both the science topic and the NOS.

For the lesson plan of the SK category of RFN, teacher Aylin collaborates with teacher Deniz. They select a 7th-grade science topic: the historical development of the atom. The MoE objective is "Students will be able to question how ideas about the concept of the atom have changed from past to present." The NOS objectives are “Students explain the developmental processes of scientific knowledge," “Students explain how different types of knowledge contribute to scientific understanding," “Students explain the difference between theories and laws," and “Students explain the role of models as a type of scientific knowledge.” The flow of the lesson plan is well organized, and the science topic is highly suitable for teaching the nature of scientific knowledge. Questions related to scientific knowledge are meaningfully sequenced from the beginning to the end of the lesson. Students make connections to the history of science, and they are shown a TLM table and watch a video about the differences between theories and laws. It can be said that teachers effectively benefit from documents about SK. Watching a video and displaying a poster on the board are good uses of technology. Although there is no group work, there are intense discussions that engage students. The assessment method is appropriate considering the objectives.

For the SI category of RFN, teacher Aylin collaborates with teacher Melisa. They select a 7th-grade science topic, which is pure substances and mixtures. The MoE objective is, “Students will be able to investigate how ideas about the concept of the atom have changed from past to present." The RFN objectives are, “Students give examples of places where scientific studies are conducted,” “Students explain the importance of sharing the results of scientific studies,” “Students offer opinions on the impact of government policy on scientific research,” and “Students explore the relationship between science and financial systems.” It is noted that the teachers do not focus directly on MoE objectives in their lesson plans; instead, they organize their lessons around the highly social-institutional aspects of science. In the assessment section of the lesson, the science topic is not referenced. Thus, the lesson plan does not include an appropriate assessment method. In the lesson plan, the teachers make a connection between atoms and CERN. They design an activity sheet that includes information about CERN and news about Türkiye’s membership in CERN. The text includes some connections to subcategories of SI. Additionally, a visual regarding social-institutional aspects of science (used during the PD program) was incorporated into the PD program. The lesson plan contains intensive discussions and question-and-answer segments but shows limited interaction among the students. It includes a variety of instructional techniques and clearly describes procedures.

For the MIX 1 lesson plan, Teacher Aylin collaborates with Teacher Beren. They selected a 5th-grade science topic, which covers the melting, freezing, and boiling points of pure substances and their graphs. The MoE objective is “Students will be able to determine the melting, freezing, and boiling points of pure substances as a result of the experiments conducted.” They focused on the AV, SP, and SI categories of RFN as NOS objectives. These are: “Students understand the goals of accuracy and scientific adequacy in relation to the reliability of scientific studies (AV);” “Students make inferences by evaluating the data from the experiments they observe (SP);” “Students predict and discuss the distinguishable properties of matter (SP);” “Students explain the importance of repeated testing (AV);” “Students give examples of places where scientific studies are conducted (SI);” “Students provide examples of the importance of scientific studies (AV);” “Students explain the importance of sharing the results of scientific studies (SI);” and “Students understand the necessity of financial support for conducting scientific studies (SI).” It is interesting that the teachers do not mention the financial aspects of science during the lesson, yet they include

it as an objective. NOS is meaningfully integrated into each part of the lesson plan. The teachers also prepare a presentation to show students pictures, graphs, and questions. Additionally, students have the chance to evaluate the results of the experiment, making predictions, inferences, and using models. The lesson plan includes diverse instructional techniques and a variety of resources/materials, integrating technology. The assessment section of the lesson plan covers both science and NOS issues together. The timing is appropriate for implementation.

For the final lesson plan MIX2, Teacher Aylin collaborates with Teacher Leyla. They select a 7th grade science topic focused on pure substances: elements and compounds. Their MoE objective is "Students will be able to classify pure substances as elements and compounds and provide examples." They prefer to select NOS objectives related to the AV, SP, and SI categories of RFN. These objectives are "Students provide examples of the purposes of science related to the reliability of scientific studies (AV)," "Students explain the importance of repeated testing (AV)," "Students recognize the importance of evaluating previous studies as a professional activity (SI)," "Students categorize scientific activities as experiments, observations, and classifications (SP)," and "Students propose suggestions for securing funding for scientific research (SI)." It is interesting that for the last two lesson plans, Aylin's groups focused on the same RFN categories. Additionally, the flow of the lesson plans shows similarities. They prepared a PowerPoint presentation to display visuals, text, and questions easily. The lesson plan includes diverse instructional techniques and a variety of resources/materials, integrating technology. In this lesson plan, they create an engaging story that captures students' attention. They make a connection to CERN, and NOS is emphasized in at least two sections of the lesson plan. The lesson plan does not include a group activity but features intense question-and-answer sessions. The assessment section of the lesson plan includes only science-based questions. The procedures are not very clear for the reader. Time is appropriate for the implementation.

Aylin's Journals

Teacher Aylin answered two fundamental questions each week about the lesson plan development process in her journals. These questions are "(1) How did you integrate this week's RFN category of science into your lesson plans? Why did you choose this specific

teaching practice, strategy, or method in your lesson plan?" and "(2) Did you face any challenges while integrating this category of science into your lesson plans? If so, at which point did you experience difficulties?" The analysis is conducted for each question separately, considering Aylin's 7-week reflections.

For the first question, teacher Aylin reflects on her ideas about integrating relevant RFN categories into lesson plans. She and her group mate incorporate the aims and values of science (Week 1) through critical thinking, scientific methods (Week 2) through experimentation, scientific practices (Week 3) through experiential practices, scientific knowledge (Week 4) through questions and answers and activity sheets, and the social institutional aspects of science (Week 5) by connecting to the scientific institution of CERN. In Week 6, they focus on the SP, AV, and SI categories of RFN, determining these categories based on the science topic. They prepare a PowerPoint presentation. In the last week, they include AV, SP, SK, and SI aspects of RFN in their lesson plans, aiming to integrate all categories to reflect their understanding of NOS.

Teacher Aylin believes that they generally pay attention to selecting teaching strategies that encourage active student participation, such as brainstorming, large group discussions, and experiment-observation activities. Additionally, teaching strategies are chosen to align with the science topic. For example, in Week 2, they prepared their lesson on hypothesis testing and manipulation to teach scientific methods. Furthermore, in Week 5, while exploring the SI, they employed brainstorming and large group discussions to help students analyze how scientific institutions like CERN contribute to the development of scientific knowledge. This encouraged students to share their thoughts and understand the collaborative nature of scientific research.

Teacher Aylin believes that they generally face challenges related to concept confusion and time management. For instance, particularly during Week 7, the team struggled to prevent concept confusion. While developing a case study to help students differentiate between elements and compounds, additional time was needed to craft a clear and logical storyline. This was essential to ensure that students could follow the sequence of events without misunderstanding key concepts. The emphasis on eliminating potential misconceptions resulted in extended planning sessions. Moreover, there were occasional

difficulties in aligning with specific learning outcomes. For example, during Week 1, the team encountered some challenges in matching the lesson content with the specific learning outcomes related to the NOS. Some objectives required more complex examples, leading to initial confusion. However, the team quickly adapted their plan by revising activities and incorporating clarifying examples, which helped them overcome the challenge. Finally, they had to adapt teaching methods considering the constraints in teachers' classrooms. For instance, in Week 6, since conducting a real experiment wasn't feasible due to time and resource limitations, they adjusted by using slides to simulate the experiment. Although this solution was effective, it necessitated careful planning to keep students engaged without the hands-on element.

Aylin's Group Discussions

Seven weeks of lesson plan group discussions were analyzed based on third themes. Regarding (1) the selection of NOS objectives, Aylin's groups consistently chose reasonable NOS objectives aligned with appropriate science content. For the AV, SP, and SI categories, she selected objectives distinct from those in the example lesson plans. However, for the M and SI categories, she heavily relied on the example lesson plans. For instance, in the M category, she preferred manipulative and hypothesis-testing methods over other approaches. It should be noted that teachers, including Aylin, faced challenges in understanding certain NOS concepts, which led to difficulties in integrating them into lesson plans effectively. For example, for the lesson planning session of the AV category, teacher Aylin determines NOS objective as:

> "Aylin: So, experimental competence, accuracy, critical thinking—these three are definite. I'm thinking, for example, if an activity is done after that movement and each group draws a conclusion and then discusses it, maybe critical thinking can come in there. Like trying to justify their claims with reasoning.
>
> Leyla: "At least we're making the groups discuss. So they're considering opposing ideas and trying to ensure the accuracy of their explanations based on some experimental aspect. Or they can check the formula from the beginning—whether it holds true. For instance, I see here that the sum of potential and kinetic energy equals mechanical energy." (group discussions, AV workshop)

For (2) the selection of activities and teaching methods, she was creative. She suggested using diverse teaching materials such as simulations and interactive smart notebooks. Because she works in a private school, her school's physical conditions were

suitable for conducting experiments, group work, and activities. Additionally, her school's structured teaching activities allowed her to integrate NOS concepts effectively. For example, in the SP lesson plan, she was already planning to conduct a parachute activity for the topic of friction force. During the planning process, she incorporated question-and-answer sessions to emphasize NOS. In her group discussions, Aylin demonstrated improvement in explicitly teaching NOS over the weeks. For example, in the AV lesson plan, she initially referenced NOS objectives only at the end of the lesson. However, in the final two weeks, she made a clear effort to emphasize NOS in each section of the lesson plan.

For (3) the assessment of NOS, Aylin generally preferred to use question and answer formats during her group discussions. They decided to employ classroom discussion as their evaluation method, believing this approach would also enable them to assess NOS outcomes. In their group discussions, they sometimes benefited from example lesson plans and visuals for assessment provided to them during the PD program. It can be said that the lesson development sessions enhanced Aylin's ability to incorporate NOS issues into her lesson plans.

4.2.1.2. Case 2 – Beren's Teaching Planning. In this session, data sources such as individual interviews, lesson plans, teacher journals, and group discussions are analyzed to investigate how Teacher Beren incorporates NOS activities into her lesson plans while participating in the online reflective collaborative professional development program, structured by the RFN framework. Teacher Beren only teaches 5th graders at her school. Therefore, she collaborated with teachers Aylin, Leyla, Melisa, and Zeynep in the lesson plan development sessions.

Beren's Individual Interviews

Teacher Beren effectively demonstrates her confidence in integrating NOS into her teaching without requiring extensive preparation. She highlights how NOS-related concepts are already embedded in lesson plans and emphasizes her commitment to naturally incorporating these ideas when relevant. Her approach to engaging students by encouraging them to think like scientists shows a strong understanding of inquiry-based learning. On the

other hand, because NOS is not directly aimed at teaching in the science curriculum, it does not seem like the main objective of the science lesson. She states her ideas as follows:

> "Honestly, I don't think I will need any special preparation to integrate NOS objectives into my lessons. If I come across moments where I can naturally highlight them, I will do so. I have also noticed that children love the idea of being scientists. I plan to emphasize this in my lessons by asking questions like, 'If you were a scientist, what do you think is being investigated in this experiment?' or 'If you observed this, what conclusions would you draw?'. I believe these small discussions can be engaging for students. Professionally, I see this PD program not as a lesson-planning course but to understand and teach the NOS more effectively. And I have gained exactly what I expected from it. I believe it has contributed to my professional development, and I will naturally incorporate what I have learned into my teaching. When reviewing units and planning lessons, I think every teacher who attended this training will recall key points. … I also plan to place strong emphasis on the SI aspects of science. Students are already fascinated by historical scientific developments and how things have evolved. I will also continuously highlight the AV of science, emphasizing that scientists do not reach the truth in a single step and that science is always subject to change." (Beren, post-interview)

Additionally, she reflects a deep appreciation for the PD program's impact on her professional growth, noting that it has strengthened her understanding of NOS instead of focusing solely on lesson planning. Overall, she demonstrates a thoughtful and practical approach to integrating NOS into teaching while valuing the professional development gained from the program.

Beren's Lesson Plans

Beren worked as a group with teachers Aylin, Leyla, Melisa, and Zeynep during the lesson planning sessions. Her and her group members' scores for each lesson plan gathered from the Lesson Plan Assessment Rubric are presented in Table 4.34. The lesson plans are evaluated and summarized based on the items in the Lesson Plan Assessment Rubric.

For the lesson plan about the AV category of RFN, Teacher Beren collaborates with Zeynep Teacher. They select the 5th grade science topic of "Measurement of Force and Friction Force." The MoE objectives are "Students will be able to explore the effect of frictional force on motion in different environments through experiments." and "Students will be able to generate new ideas to increase or decrease friction in daily life." The RFN objectives are "Students will be able to explain the importance of repeated testing." and "Students will be able to design a new product to solve a problem based on human needs." It can be said that all stated RFN objectives are covered in the lesson plan, and NOS issues

are referred to in different sessions of the lesson plan. The lesson plan includes a variety of resources and materials that integrate technology. For example, in the engagement part of the lesson, students watch a video about friction force. In the exploration phase of the lesson, students are treated as scientists and are asked to design a project related to friction force to address human needs. Students are divided into three groups, and each group is provided with materials to experience friction on air, liquid, and solid surfaces. Group work ensures that students remain actively engaged in their learning process. In the explanation phase, groups present their designs and give examples of situations that increase or decrease friction in different environments. At the end of this phase, a clear emphasis is placed on the NOS. The assessment section of the lesson is not fully developed to cover all learning objectives; it consists only of questions related to scientific content. The lesson duration is appropriate for implementation.

The lesson plan about the M category of RFN is prepared by teacher Melisa. They selected a 5th-grade science topic. The MoE objectives are “Students will be able to provide examples of frictional force from daily life.” and “Students will be able to explore the effect of frictional force on motion in different environments through experiments." The NOS objectives are “Students will be able to formulate a testable hypothesis.”, “Students will be able to recognize the role of variables in an experimental setup.” and “Students will be able to express that different scientific methods can be used to answer a research question." It is evident that teachers focus on experimental methods in their NOS objectives. In the lesson plan, all stated RFN objectives are referenced. The lesson plan clearly describes the students' prior knowledge and the procedures. The teacher conducts the experiment while students make observations, predictions, and record their findings in their activity sheets. The activity integrating the RFN category into the scientific topic is appropriate. On the other hand, NOS issues are covered only in the exploration part of the lesson plan. The assessment section includes only science-based questions. The lesson plan incorporates a variety of resources/materials and integrates technology. Students watch videos from EBA about the advantages and disadvantages of frictional force. There is no group work; teachers probably considered the physical conditions of their classrooms, but students are encouraged to be active through questions and answers. The duration is suitable for implementation.

Table 4.34. Beren's lesson score for each lesson plan.

Group members with Beren	**Zey.**	**Mel.**	**Ley.**	**Mel.**	**Zey.**	**Ayl.**	**Zey.**
Item of assessment rubric/LP	LP1 (AV)	LP2 (M)	LP3 (SP)	LP4 (SK)	LP5 (SI)	LP 6 (MIX1)	LP 7 (MIX2)
The lesson plan explicitly states MoE learning objectives.	3	3	3	3	3	3	3
The lesson plan explicitly states RFN learning objectives.	3	3	3	3	3	3	3
All stated RFN objectives are covered in the lesson plan / all taught RFN objectives are explicitly listed in the RFN objectives section.	3	3	2	3	3	2	3
The lesson plan clearly describes prior knowledge of the students.	3	3	3	3	3	3	3
The lesson plan clearly describes procedures.	3	3	3	3	3	3	2
The activity in integrating of RFN category to the scientific topic is appropriate.	3	3	3	3	3	3	3
The RFN category is referred at least two parts of the lesson plan.	2	1	3	3	3	3	3
The lesson plan includes variety of resources/materials integrating technology.	3	3	3	3	3	3	3
The lesson plan promotes active engagement of students.	3	2	3	2	2	2	2
The lesson plan includes a variety of instructional techniques.	3	3	3	3	2	3	3
The lesson plan includes appropriate assessment methods.	2	2	2	3	3	3	3
RFN objectives are assessed during the assessment part of the lesson.	1	1	1	3	3	3	3
The lesson plan is instructionally appropriate in terms of time management.	3	3	3	3	3	3	2
Total Score:	35	33	35	38	37	37	36

The lesson plan for the SP category of RFN is completed with Teacher Leyla. They selected a 5th-grade science topic from the unit "Matter and Change." The science objective is "Students will be able to make inferences based on data obtained from experiments that show how substances can change state due to heat." The NOS objectives are "Students will be able to establish a connection between the scientific practices they have used during the activities and the Benzene Ring Analogy," and "Students will be able to explain the theory-laden nature of classification as a scientific practice." The second NOS objective is not

explicitly emphasized during the lesson. NOS emphasis occurs in both the exploration and explanation parts of the lesson plan, but not in the assessment. The evaluation component includes only science-based questions. The lesson plan clearly describes the students' prior knowledge and the procedures. It incorporates a variety of resources and materials, integrating technology. Teachers prepare a PowerPoint presentation, show different videos for each phase change, and use many visuals from daily life examples. The lesson plan also promotes active participation among students. In the exploration part of the lesson, students work in pairs to classify examples according to phase change. The duration of the lesson is appropriate for implementation.

For the lesson plan SK of RFN, teacher Beren worked with teacher Melisa. They selected a 5th grade science unit titled “Matter and Change.” The MoE objective is "Students will be able to make inferences based on data obtained from experiments that show how substances can change state due to heat." The NOS objectives are "Students will be able to explain the difference between scientific knowledge and scientific law," “Students will be able to explore that a scientific law generally describes facts, while a scientific theory explains the law/facts,” and “Students will be able to explain how different types of knowledge contribute to scientific understanding." NOS issues refer to different parts of the lesson plan. The lesson plan clearly describes the prior knowledge of the students and the procedures. In the engagement part, students are provided with daily life examples, which attract them to the science topic. In the exploration part, students are asked questions about different types of scientific knowledge, and they watch a video about casual and scientific uses of theory and law. Additionally, they use the TLM wall visual to show how theories, laws, and models work together to provide scientific understanding. It can be said that they are influenced by the PD program, during which teachers watched a video about the differences between theories and laws. Similarly, the TLM wall picture also served as a pedagogical tool. Thus, the lesson plan includes a variety of resources and materials that integrate technology. The evaluation part includes both science and NOS-based questions. Students are encouraged to be active through question-and-answer sessions. The duration is suitable for implementation.

For the lesson plan SI, Teacher Beren collaborates with Teacher Zeynep. For the same unit, the MoE objective is “Students will be able to determine the melting, freezing,

and boiling points of pure substances as a result of the experiments conducted.” The NOS objectives are "Students will be able to explain the importance of sharing the results of scientific studies," “Students will be able to understand that scientific research serves humanity," “Students will be able to grasp the principles of universality and respect for colleagues as scientific values," “Students provide examples of places where scientific research is conducted," and “Students conclude that there are financial requirements for scientific research." It is noted that NOS issues are mentioned in both the development and result sections of the lesson plan. Most of the NOS questions are listed in the results section, apart from the lesson activity and science topic. The activity utilizes interactive videos from the EBA. Thus, the lesson plan includes a variety of resources and materials that integrate technology. Students are active in answering science-based questions on the smart board and NOS questions directed by their teacher. However, interaction among them is limited. The lesson plan clearly describes the prior knowledge of the students and the procedures. Overall, the lesson plan is instructionally appropriate in terms of time management.

For the lesson plan MIX1, teacher Beren collaborates with teacher Aylin. They focus on the 5th-grade science topics of melting, freezing, and boiling points of pure substances and their graphs. The evaluation of the lesson plan is provided under the title of Aylin’s lesson plans.

In the final lesson plan of MIX2, teacher Beren collaborates with teacher Zeynep to select 5th grade science topics. The MoE objectives are “Students will be able to conduct experiments to observe the expansion and contraction of substances due to heat and discuss the results.” and “Students will be able to relate examples from daily life to the phenomena of expansion and contraction.” The NOS objectives include “Students will be able to formulate a testable hypothesis (M)”, “Students will be able to represent the scientific methods they used in their activities within Brandon’s matrix (M)”, “Students will be able to identify the scientific methods they used in their activities (M)”, “Students will be able to explain the importance of repeated testing (AV)”, “Students will be able to propose suggestions regarding the purposes of scientific studies (AV)”, “Students will be able to categorize scientific activities into experiments, observations, and classifications (SP)”, and “Students will be able to recognize the benefits of the topic 'Heat Affects Matter' for humanity (SI).” This lesson plan aims to teach four different NOS categories. In the

engagement part of the lesson plan, examples from daily life are provided, and brainstorming sessions are conducted. The exploration part involves a simulation from the EBA, where students are asked to make inferences, construct, and test their hypotheses. Here, students are expected to experience scientific practices and experimental methods. It can be challenging for 5th grade students to construct and test their hypotheses through simulation if they lack prior knowledge about determining variables, constructing hypotheses, and understanding Brandon's matrix. Therefore, it is necessary to provide details about the procedures. The RFN category is referenced in the explanation, elaboration, and evaluation parts of the lesson plan. While there is no group activity, students engage in intense question and answer sessions. The integration of the RFN category into the scientific topic is appropriate, and the lesson plan includes various instructional techniques such as brainstorming, simulations, and discussions. The evaluation section contains many exercise questions, so the duration needs to be extended.

Beren's Journals

The reflective responses submitted over the seven weeks demonstrate a progressive approach to integrating the NOS into lesson plans. This evaluation summarizes the findings for each question separately.

Teacher Beren reflects on her ideas about how to integrate the NOS category into their lesson plans. She and her group mate incorporate the aims and values of science (Week 1) through questioning; scientific methods through experimentation (Week 2); scientific practices through modeling, watching videos, and experiencing different scientific practices (Week 3); scientific knowledge through traditional teaching methods; and social-institutional aspects of science through questioning. For the MIX1 lesson plan, they prefer to refer to AV, SP, and SI of RFN. In the last lesson plan, she and her group member focus on AV, M, SP, and SI of science. She believes that these aspects of science are more suitable for integrating science content. Throughout the seven-week lesson planning process, the teacher carefully selected specific teaching strategies, methods, and approaches to incorporate the NOS into their lessons. Their choices were primarily influenced by the effectiveness of these methods in promoting student engagement and understanding. For example, they frequently used questioning, interactive videos, and whole group discussions because these approaches allow students to explore scientific concepts actively and

critically. Additionally, hands-on experiments were chosen to help students experience the process of scientific discovery firsthand. The teacher also emphasized the importance of historical case studies to illustrate how scientific knowledge evolves, believing that real-world examples make abstract NOS concepts more tangible for students.

Despite their best efforts, teacher Beren faced challenges in integrating NOS into her lesson plans. Initially, she found it difficult to refer to specific NOS categories—such as the aims and values category of science—thinking that the questions about aims and values lack depth. For the scientific methods category of science, she struggled to integrate scientific methods without disrupting the lesson flow. In the scientific practices category of RFN, she could easily integrate scientific practices into her lesson but struggled to find appropriate assessment tools to measure students' understanding of NOS. Thus, she generally benefits from the example lesson plans examined through the PD program. Another challenging issue is making connections between the science topics she has to teach in her school and the NOS categories. She has difficulty connecting the topic of phase change to the scientific knowledge category of science. For the SI category, she thinks it is easy to integrate into her science lesson plans. For the last two lesson plans, she believes her group can easily integrate NOS categories into the lesson plan because they selected which NOS categories they would teach.

Beren's Group Discussions

Beren, in her 7-week lesson planning sessions, was very active. She paid attention to developing lesson plans that considered her school's physical conditions and students' profiles. For the selection of NOS objectives, she and her group members focused on the best integration of NOS objectives into lesson plans. The group discussions indicated that, for the AV, M, and SK categories of NOS, they greatly benefited from the example lesson plans. For the final two MIX lesson plans, she and her group members concentrated on teaching the AV, SP, and SI categories. In her group discussions, it was clear that she prioritized developing lesson plans collaboratively.

For the selection of NOS activities and teaching methods, Teacher Beren tailored her approach to accommodate crowded classrooms, prioritizing practical teaching strategies. She avoided group work, favoring whole-class discussions, simulations, and question-and-

answer sessions instead. Therefore, her group discussions with Teacher Zeynep were sometimes challenging because Teacher Zeynep tended to conduct her favored activities for specific science topics. Due to limited access to school internet, she prepared PowerPoint presentations in advance. Beren ensured that NOS categories were explicitly and coherently integrated into science topics, thoroughly detailing procedures in her lesson plans. During group discussions, she drew on examples from PD workshops and lesson plans to refine her planning. The following group discussion provides information about how Teacher Beren and her group member collaboratively integrate NOS into their lesson plans.

> "Beren: Maybe before starting the "exploration" phase, the teacher could first give a general explanation to the class about what will be done. Like, we have human needs, and we need to generate problems related to these needs. Then say: Here are some problems distributed to you, and you will design a tool for them. From there we can connect to NOS...
>
> Zeynep: That could work. Also, in the explanation part, after the explore phase, each group will present their experiment, right? During this, they could explain the challenges they faced while developing their product. We can reinforce it by asking questions like: Why did you test it multiple times? Why didn't it work the first time?
>
> Beren: We can address it in both the explore and explain phases. In the explore phase, we give the introduction: Right now, you are producing a new product in response to a human need, just like a scientist or an explorer would. And at the end, we could say that science also develops this way—by addressing human needs. It doesn't work the first time; you have to try more than once." (group discussion, AV workshop)

Teacher Beren encountered difficulties in creating assessment tools for particular NOS objectives in certain lesson plans. During group discussions, her team usually assessed NOS objectives through question-and-answer sessions or targeted worksheet questions.

4.2.1.3. Case 3 – Deniz's Teaching Planning. In this session, data sources such as individual interviews, lesson plans, teacher journals, and group discussions are analyzed to investigate how Deniz incorporates NOS activities into her lesson plans while participating in the online reflective collaborative professional development program structured by the RFN framework. Deniz, who works at her school, teaches only 7th graders. Thus, she collaborated with teachers Aylin, Leyla, and Melisa during lesson plan development sessions.

Deniz's Individual Interviews

Deniz provides a thoughtful reflection on her growth through the professional development (PD) program and its impact on both her teaching practices and lesson

planning. She demonstrates an improved understanding of the NOS and its value in fostering student engagement and curiosity. By moving beyond merely following the national curriculum and actively incorporating NOS, she has noticed a positive shift in student participation and interest, even among more passive learners. Her emphasis on interactive methods such as discussions, videos, and experiments shows a clear transition from traditional teaching to more engaging, inquiry-based learning. She shares her thoughts as:

> "I used to follow the national curriculum (MoE) objectives and only include NOS when explicitly mentioned. Now, I realize NOS isn't emphasized enough, so I've started creating my own lesson plans to raise awareness. I've noticed that students really enjoy lessons with NOS integration, even if the topics are new to them. Activities, discussions, and debates increase their participation, and I see their curiosity grow. NOS sparks interest, encourages questioning, and helps students connect concepts. I plan to continue applying what I've learned, as it has increased awareness for both me and my students. Even the most passive students have started engaging more. Using videos, experiments, and news articles captures their attention and shifts their perspective on science. Overall, integrating NOS alongside the curriculum has proven highly beneficial." (Deniz, post-interview)

Additionally, she acknowledges the wider benefits of integrating NOS, including the development of awareness in both them and their students. Overall, she emphasizes the effectiveness of the PD program in not only enhancing teaching strategies but also promoting a more student-centered approach to science education.

Deniz's Lesson Plans

Deniz worked as a group with teachers Aylin, Leyla, and Melisa during the lesson planning sessions. Her score and that of her group members for each lesson plan, gathered from the Lesson Plan Assessment Rubric, are presented in Table 4.35. The lesson plans are evaluated and summarized based on the criteria in the Lesson Plan Assessment Rubric.

In the lesson plan about the AV of RFN, teacher Deniz collaborates with teacher Melisa. They selected a 7th grade science topic for the unit on Force and Energy. The MoE objective is "Students will be able to explain that work, in a physical sense, is related to the applied force and the distance covered." The NOS objectives are "Students will be able to explain the importance of repeated testing (Reliability)," "Students will be able to seek new explanations related to the concept of work (Innovation)," "Students will be able to provide reasons to support their opinions/predictions (Critical thinking)," "Students will be able to

explain that scientific studies can be aimed at meeting human needs (Addressing human needs),” and “Students will be able to base their predictions on sufficient, relevant, and reasonable data (Experimental proficiency).” In their lesson plan, the teachers state many objectives for AV of science; however, they do not explicitly refer to each objective during the lesson plan. For example, regarding the last objective of experimental proficiency, students discuss whether or not there is physical work for the given examples, considering the simulation data. However, it is not explicitly mentioned that this is done for the aims and values of science. Additionally, some objectives, such as addressing human needs, are not referred to during the lesson plan; this objective is only referenced in the assessment part of the lesson plan. The lesson plan clearly describes the prior knowledge of the students and the procedures. The simulation activity integrating the RFN category with the scientific topic is appropriate. Based on the simulation observation, students discuss and reach a consensus. The lesson plan includes a variety of resources and materials, integrating technology. The teachers plan to use EBA in their lessons. The lesson plan promotes active student engagement through group activities.

In the lesson plan for the M category of RFN, teacher Deniz collaborates with teacher Leyla. They selected a 7th grade science topic for the unit “Pure Substances and Mixtures." The MoE objective is “Students will be able to describe the structure of the atom and its fundamental particles." The NOS objectives are "Students will be able to discover subatomic particles based on sufficient, relevant, and reasonable data (Experimental competence)" and “Students will be able to explain different scientific methods." It is noted that the teachers refer to the NOS objectives in different parts of the lesson plan. In the lesson plan, the teacher shows an image illustrating the particulate nature of matter and emphasizes that all matter is made up of particles. After defining the concept of the atom, worksheets are distributed to students. In the worksheet, the developmental process of the atom and its particles is explained, and students are asked to answer three questions about the text. The text pertains to the reliability of scientific knowledge through empirical competence. In the explanation section, information about the three sub-particles of the atom is provided. Additionally, the Brandon matrix is introduced to students, with examples given of different scientific methods. In the elaboration section, a text about CERN is read. Through this text, students gain knowledge of how scientific methods are used to explore the nature of atoms. Teachers prepare some questions regarding both science and scientific methods for the evaluation part

of the lesson. It is observed that one of the questions concerning the scientific method is similar to an example lesson plan shown during the PD program. The lesson plan includes a variety of resources and materials integrating technology, such as activity sheets, PowerPoint presentations, etc. The lesson plan promotes the active engagement of students through question-and-answer sessions. The duration is appropriate for implementation.

Table 4.35. Deniz's lesson score for each lesson plan.

Group members with Deniz	**Mel.**	**Ley.**	**Ayl.**	**Ayl.**	**Ley.**	**Ley.**	**Mel.**
Item of assessment rubric/LP	LP1 (AV)	LP2 (M)	LP3 (SP)	LP4 (SK)	LP5 (SI)	LP 6 (MIX1)	LP 7 (MIX2)
The lesson plan explicitly states MoE learning objectives.	3	3	3	3	3	3	3
The lesson plan explicitly states RFN learning objectives.	3	3	3	3	3	3	3
All stated RFN objectives are covered in the lesson plan /all taught RFN objectives are explicitly listed in the RFN objectives section.	2	3	2	3	3	3	3
The lesson plan clearly describes prior knowledge of the students.	3	3	3	3	3	3	3
The lesson plan clearly describes procedures.	3	3	3	3	3	3	3
The activity in integrating of RFN category to the scientific topic is appropriate.	3	3	3	3	3	3	3
The RFN category is referred at least two parts of the lesson plan.	3	3	1	3	1	2	3
The lesson plan includes variety of resources/materials integrating technology.	3	3	3	3	2	2	3
The lesson plan promotes active engagement of students.	3	2	3	2	2	2	3
The lesson plan includes a variety of instructional techniques.	3	3	3	3	2	3	3
The lesson plan includes appropriate assessment methods.	3	3	3	3	3	3	3
RFN objectives are assessed during the assessment part of the lesson.	2	3	3	3	3	3	3
The lesson plan is instructionally appropriate in terms of time management.	3	3	3	3	2	3	3
Total Score:	37	38	36	38	34	37	39

In the lesson planning for the SP category of RFN, Teacher Deniz collaborated with Teacher Aylin on the topic of friction force for 7th-grade students. The evaluation of the lesson plan is provided under the title Aylin's lesson plans.

For the lesson plan of the SK category of RFN, Teacher Deniz collaborates with Teacher Aylin on the 7th-grade science topic of the atom. The evaluation of the lesson plan is provided under the title Aylin's lesson plans.

For the lesson plan for SI of RFN, teacher Deniz collaborates with teacher Leyla. They determine the 7th grade science topic for the unit on "Pure Substances and Mixtures." The MoE objective is "Students will be able to identify the names, symbols, and some uses of the first 18 elements in the periodic table and common elements (gold, silver, copper, zinc, lead, mercury, platinum, iron, and iodine)." The NOS objectives encompass several subcategories concerning the social-institutional aspects of science. These are "Students identify that scientists work with social groups within social institutions," "Students will be able to provide examples of places where scientific research is conducted," "Students will be able to recognize that scientists engage in professional activities to present their work," "Students will be able to realize that evaluating scientific research requires a set of standards," "Students will be able to become aware of the financial aspect of science," and "Students become aware of the political aspect of science." The lesson starts by showing the periodic table to students and asking questions about how these elements are symbolized. In the exploration part of the lesson, students learn about the origins of the names of elements and how they are symbolized with examples. In the explanation part of the lesson, the teacher provides a general overview of the symbolism of the elements. During the elaboration of the lesson, a worksheet that includes an article published by Bilim Genç is distributed to students. After reading the text, students are expected to answer questions related to the SI aspects of science in the evaluation part. The worksheet contains both science and NOS-based questions. It is noted that NOS issues are not emphasized in different parts of the lesson plan. The lesson plan includes a limited range of resources/materials integrating technology. Students are encouraged to be active through questions and answers. The duration is set at 40 minutes, but it is necessary to extend it to 2 lesson hours to make discussions more effective.

For the MIX1 lesson plan, teacher Deniz collaborates with teacher Leyla on a 7th-grade science topic. They continue the same unit on “Pure Substances and Mixtures.” The MoE objective is "Students will be able to state that identical or different atoms can combine to form a molecule." The NOS objectives are "Students will be able to explain the role of modelling in scientific studies by conveying the challenges of observing and studying certain scientific concepts (SP)," “Students will be able to explain the importance of sharing the results of scientific studies (SI)," and “Students will be able to represent the scientific methods they use in their activities within Brandon's Matrix (M)." The teachers focus on three different RFN categories in this lesson plan. In the introduction, they use an analogy between molecules and logo particles and provide examples of molecules, elements, and compounds. In the development section of the lesson, students are treated as scientists and are asked to classify 12 molecules as atomic or compounds to gain permission from a scientific community. In the results part of the lesson, students are directed with questions about SI aspects of science, such as "What is the importance of presenting the classification work to the scientific committee? What criteria do you think the scientific committee will focus on while evaluating your classification and explanations?" In the results section, assessment is conducted through science and NOS-based questions. The procedure of the lesson plan is clear. Students are engaged through questions and answers. The duration is instructionally appropriate.

For the MIX 2 lesson plan, teacher Deniz works with teacher Melisa on the 7th grade science topic. She continues the same unit, “Pure Substances and Mixtures.” The MoE objectives are, “Students will be able to state that identical or different atoms can combine to form a molecule,” and “Students will be able to create and present various molecule models." The NOS objectives are: "Students will be able to make inferences about molecules by utilizing modeling (SP),” “Students will be able to group scientific activities as experiments, observations, and classifications (SP),” “Students will be able to explain the importance of sharing the results of scientific studies (SI),” and “Students will be able to establish a connection between the scientific practices they used during the activities and the Benzene Ring Heuristics (SP).” In the introduction to the lesson, teachers use an analogy with molecules and succulents made from LEGO through brainstorming. In the development phase, students work in groups. They are expected to model their molecules using playdough and present their models to other groups. During this part of the lesson, the teacher asks

questions related to NOS, such as, "What are the similarities and differences between your models? If we wanted to create a common model structure as a class, what would our criteria be?" The teacher provides explanations through a video from EBA. In the results section of the lesson plan, students are asked to fill out a table about molecules and respond to questions about NOS. The Benzene Ring Heuristics is used as a pedagogical tool to evaluate the lesson. The lesson plan clearly describes students' prior knowledge and procedures. A variety of resources and materials incorporating technology is used, such as visuals, videos, and worksheets. The duration is suitable for implementation.

Deniz's Journals

Teacher Deniz reflects on her ideas regarding the integration of NOS into her lesson plans. For the AV of science, her group employs questioning, simulation, and classical teaching techniques. For the M category of RFN, they use the Brandon matrix, questioning, and examples from the history of science. In the SP category of RFN, they utilize BRH and create their models. For SK of RFN, they employ questioning through texts, and for SI of RFN, they question through news about science. For the MIX1 lesson plan, they prefer to select objectives for the SP, SK, and SI categories of science, as the science topic influences their decisions. Similarly, for the MIX2 lesson plan, her groups choose SP and SI categories of RFN. She describes the teaching strategies they utilize in their lesson plans, which are greatly influenced by the science topic, student engagement, and resource availability. In Week 1, strategies are selected based on the subject matter and institutional constraints, incorporating technology for effective time management. In Week 2, they employ questioning, simulation, and classical teaching techniques, integrating the Brandon Matrix in the lesson elaboration. In Week 4, they utilize questioning through a text, and in Week 5, discussion and brainstorming are chosen as optimal methods for teaching the SI aspects of science. By the final weeks, the strategies become more refined, blending multiple instructional techniques such as prediction-based questioning and model creation to encourage active participation and conceptual understanding. She reflects on her ideas for the integration of scientific methods into the lesson plan in Week 2 as:

> "We integrated Brandon's Matrix into the explanation section of the lesson plan. The learning outcome stated that students should design a particle model of the atom. To achieve this, we provided a historical text explaining the structure of the atom and asked students to create a model based on it. Our main goal was to emphasize the diversity of scientific methods by encouraging students to analyse the text and identify the specific scientific method used within it." (Deniz, teacher journal, week 2)

Challenges varied across weeks but were generally related to assessment alignment, differentiation from prior plans, and sourcing relevant materials. In week 1, difficulties arose in designing assessments that accurately measured understanding of the AV of science. Conversely, weeks 2 and 3 presented fewer challenges, as the topics lent themselves well to modeling and hands-on experimentation. By week 5, the primary struggle was finding suitable external sources, such as relevant news articles. The most significant difficulty appeared in week 7, where avoiding redundancy from previous lesson plans required additional creativity. The responses indicate that while the integration process became smoother over time, maintaining originality and effective assessment design continued to be areas of difficulty.

Deniz's Group Discussions

In her pre-interview, Teacher Deniz described her typical teaching strategies as mainly didactic, relying on direct instruction. Throughout the seven weeks of lesson development sessions, she actively worked to diversify her teaching methods, demonstrating openness to new ideas and critically evaluating suggestions for practicality. During group discussions, Deniz consistently considered her classroom dynamics, her school's physical conditions, and her students' profiles when shaping lesson plans. Instead of proposing novel ideas herself, she primarily took on the role of refining and evaluating her group members' suggestions, ensuring alignment with practical constraints and NOS integration goals. For instance, when a group member suggested an inquiry-based activity for an NOS objective, Deniz assessed its feasibility given her large class sizes and limited resources, proposing modifications to make it more manageable while retaining its focus on NOS.

In her group discussions, Teacher Deniz and her group members selected (1) NOS objectives by prioritizing their alignment with science topics. Their approach involved first designing an activity related to a scientific concept and then determining how to integrate the NOS objectives into it. For example, for a lesson plan incorporating the SK category of

NOS, her group selected NOS objectives consistent with the example lesson plan. During these discussions, Teacher Deniz frequently drew on the NOS objectives provided in PD workshop presentations and example lesson plans, adapting them to fit her classroom context. Her active engagement in evaluating and refining these objectives fostered collaborative decision-making, ensuring that the objectives were both relevant to the science curriculum and feasible for her students. For the lesson planning session of the SI category, teacher Deniz tries to determine NOS objectives as:

> "Deniz: Alright, let's say, which countries care about these elements? That would be political power structures. Because, for example, Büşra Teacher talked about why China and the USA care about space mining? Political power structures...
>
> Leyla: Yes. Would it benefit them? Like you said, honoring increases its popularity. And we could ask this question: Would it be beneficial for governments to cooperate on elements for the benefit of humanity? That could be an extra question. If they work together, they could develop more, and so on.
>
> Deniz: Exactly. Let me see if that fits in. I was thinking, would it fit under scientific and social values? Because respect for the environment, for example, countries must also be respectful of each other." (group discussions, SI workshop)

Teacher Deniz, recognizing the impracticality of group work in her crowded classrooms, generally preferred whole-class discussions and teacher-led hands-on activities over small group tasks. However, she remained open to exploring diverse teaching methods. Throughout the seven weeks of lesson development sessions, she became more skilled at integrating NOS into activities, increasingly incorporating NOS-focused questions to enhance student understanding. In group discussions, Deniz collaborated with her group members, actively contributing by evaluating proposed activities for their feasibility and alignment with NOS goals, which fostered a productive planning environment.

Deniz faced challenges incorporating NOS-specific assessment tools into her lesson plans. During group discussions, likely due to time constraints, her team generally relied on question-and-answer sessions as their primary assessment method. However, in some lesson plans, they integrated assessment tools, such as the BRH from example lesson plans, to evaluate NOS objectives more systematically.

4.2.1.4. Case 4 – Leyla's Teaching Planning. In this session, data sources such as individual interviews, lesson plans, teacher journals, and group discussions are analyzed to investigate

how Teacher Leyla incorporates NOS activities into her lesson plans while participating in the online reflective collaborative professional development program structured by the RFN framework. Teacher Leyla works with 5th and 7th graders at her school. Therefore, she collaborates with all teachers in lesson plan development sessions.

Leyla's Individual Interviews

In her post-interview, Teacher Leyla noted that the professional development program has positively impacted both her approach to lesson planning and the integration of NOS into the classroom. She acknowledges the importance of asking critical questions to encourage students' curiosity and engagement with scientific content, even when the topics may differ. This approach reflects a growing awareness of the significance of NOS, not as an additional curriculum element, but as an inherent part of fostering a deeper understanding. The teacher also emphasizes the importance of creating a more structured and organized lesson plan, which ensures active student participation and the assessment of learning outcomes. Thus, she feels more confident and relaxed. She articulates her thoughts in this manner:

> "Definitely... Even if the content or the topic is different, I believe it's necessary to ask one or two questions related to the NOS… My awareness of the NOS has increased. I now feel more equipped to evaluate scientific studies and critically assess them, especially realizing that I shouldn't trust every scientific study I see. The planning has become more organized. When considering a typical 40-minute class, there is now a clear introduction to warm up the students, followed by a process where students actively engage with the material, and most importantly, an assessment of the outcomes. This has resulted in a more structured and systematic approach. … I was able to convey the topic well, or at least to the best of my ability at this point. This gave me a nice sense of assurance and relief in my conscience." (Leyla, post-interview)

She also shares her experiences integrating diverse RFN categories into her lesson plans. She believes that incorporating social-institutional aspects of science and scientific practices is the easiest category to integrate because students are more familiar with these concepts. In contrast, the categories of scientific knowledge, scientific methods, and aims and values are more challenging due to their theoretical aspects, especially for 5th-grade students. She states her ideas as follows:

> "I think the easiest part is the SI of science. I'm aware there are many, but at least I can touch on a few parts in the lesson plans. Another easier part was the scientific practices because these are things the children are already familiar with. But SK, such as theory and laws, seemed a bit advanced for them. We could talk about their definitions, but especially in 5th grade, it was more like they just heard about it. They encountered it but didn't fully grasp it. It's important, of course, but they struggled to understand it. Another aspect... they understood Brandon's Matrix. As I mentioned, they understood it through scientific studies. But still, when it comes to changing variables and forming hypotheses, they're not that good. They might be able to evaluate an existing study based on hypotheses and variables, but if we ask them to formulate their own hypotheses or identify and change variables, they might struggle. Another area is the AV of science. Some aspects of the AV of science are clear, such as its universality and the objectivity of knowledge. But I think they will struggle to understand some of the more complex aspects." (Leyla, post-interview)

The teacher, Leyla, demonstrates a commitment to continually adapting NOS teaching and creating a more engaging and meaningful learning experience based on her interview responses. Overall, the PD program seems to have significantly influenced the teacher's professional growth and inspired a more inquiry-based and reflective approach to teaching.

Leyla's Lesson Plans

Leyla worked as a group with all the teachers during the lesson planning sessions. Her and her group members' scores for each lesson plan gathered from the Lesson Plan Assessment Rubric are provided in Table 4.36. The lesson plans are evaluated and summarized by considering the items in the Lesson Plan Assessment Rubric.

For lesson plan AV, teacher Leyla collaborates with teacher Aylin. They work on the 7th-grade science topic of conservation of energy. The evaluation of the lesson plan is provided under the title of Aylin's lesson plans.

In the lesson plan for the M category of RFN, teacher Leyla collaborates with teacher Deniz. They selected the 7th-grade science topic for the unit "Pure Substances and Mixtures." The evaluation of the lesson plan is provided under the title of Deniz's lesson plans.

The lesson plan for the SP category of RFN is finalized with teacher Beren. They selected the 5th grade science topic from the unit "Matter and Change." The evaluation of the lesson plan is provided under the title of Beren's lesson plans.

Table 4.36. Leyla's lesson score for each lesson plan.

Group members with Leyla	**Ayl.**	**Den.**	**Ber.**	**Zey.**	**Den.**	**Den.**	**Ayl.**
Item of assessment rubric/LP	LP1 (AV)	LP2 (M)	LP3 (SP)	LP4 (SK)	LP5 (SI)	LP 6 (MIX1)	LP 7 (MIX2)
The lesson plan explicitly states MoE learning objectives.	3	3	3	3	3	3	3
The lesson plan explicitly states RFN learning objectives.	2	3	3	3	3	3	3
All stated RFN objectives are covered in the lesson plan / all taught RFN objectives are explicitly listed in the RFN objectives list.	1	3	2	3	3	3	3
The lesson plan clearly describes prior knowledge of the students.	3	3	3	3	3	3	3
The lesson plan clearly describes procedures.	3	3	3	3	3	3	3
The activity in integrating of RFN category to the scientific topic is appropriate.	3	3	3	3	3	3	3
The RFN category is referred at least two parts of the lesson plan.	1	3	3	3	1	2	3
The lesson plan includes variety of resources/materials integrating technology.	3	3	3	3	2	2	3
The lesson plan promotes active engagement of students.	3	2	3	2	2	2	2
The lesson plan includes a variety of instructional techniques.	3	3	3	3	2	3	2
The lesson plan includes appropriate assessment methods.	3	3	2	3	3	3	2
RFN objectives are assessed during the assessment part of the lesson.	3	3	1	3	3	3	1
The lesson plan is instructionally appropriate in terms of time management.	3	3	3	3	2	3	3
Total Score:	34	38	35	38	34	37	34

For the lesson plan SK, teacher Leyla collaborates with teacher Zeynep. They selected a 5th-grade science topic. The MoE objective is, "Students will be able to conduct experiments to observe heat transfer resulting from the mixing of liquids at different temperatures and interprets the results." The NOS objectives are, "Students will be able to explain different types of knowledge." and "Students will be able to explain the differences between theory, law, and model." In the lesson plan, NOS is referenced in different parts of the lesson. In the engagement part of the lesson, the teacher asks questions about everyday

examples of heat transfer. In the exploration part, she makes connections to different types of scientific knowledge and encourages students to consider the meanings of theories, laws, and models. She provides information about thermodynamic laws and theories, displays a model for heat transfer, and prompts students to infer. In the explanation part, she offers explanations and provides an example. In the elaboration part, the teacher refers to the functions of different scientific knowledge and presents the TLM wall as a pedagogical tool. In the evaluation part of the lesson plan, both science and NOS-based questions are asked. The students' prior knowledge and procedures are clearly outlined. The teacher utilizes various teaching materials, including PowerPoint presentations, examples, and visuals. Instead of group activities, they prefer to engage students through question-and-answer sessions. The duration is appropriate for the implementation.

For the lesson plan for SI of RFN, Teacher Leyla collaborates with Teacher Deniz. They select the 7th grade science topic for the unit on “Pure Substances and Mixtures." The evaluation of the lesson plan is provided under the title of Deniz’s lesson plans.

For the MIX1 lesson plan, Teacher Leyla works alongside Teacher Deniz on the 7th grade science topic. They continue with the same unit on “Pure Substances and Mixtures." The evaluation of the lesson plan is provided under the title of Deniz’s lesson plans.

For the final lesson plan MIX2, Teacher Leyla partners with Teacher Aylin. They choose the 7th grade science topic of pure substances: elements and compounds. The evaluation of the lesson plan is provided under the title of Aylin’s lesson plans.

Leyla’s Journals

Teacher Leyla reflects on how she and her group member integrate NOS issues into her lesson plans in her journals. For the AV category of science, they collaborate on various projects; for the M category of RFN, they utilize the Brandon Matrix; for SP, they employ classification exercises and real-world applications; for SK, they provide examples of different types of scientific knowledge; and for SI, they engage in discussions about element naming and scientific institutions. In the MIX1 lesson plan, she and her group member focus on the SP and M categories of science. In the MIX2 lesson plan, they select the AV, SP, and

SI categories of RFN. Teacher Leyla expresses her challenges regarding the SK category of NOS as:

> "Since the topic of thermodynamics includes explanations belonging to different types of SK, we did not have difficulty establishing its connection with the lesson. The challenging part was making students recognize the differences between these types of SK. We emphasized that scientific laws describe what real-world phenomena are, theories attempt to explain why or how these phenomena occur, and models provide representative explanations of the phenomena. Scientific laws and theories, in particular, tend to be perceived as large and complex concepts by many students. With this lesson plan, we aimed to present these types of SK through cartoons, demonstrating that they are accessible concepts for students. In summary, while the topic of the lesson aligned with this aspect of the NOS, making these types of SK meaningful for students was challenging." (Leyla, teacher journal, week 4)

The teacher Leyla carefully selects instructional strategies aligned with both curricular goals and the nature of science. In week one, group work and graphical analysis are chosen to mimic scientific collaboration. Brandon Matrix in week two is used to illustrate non-experimental scientific methods, helping students appreciate diverse ways of scientific inquiry. In week three, classification and real-life applications are integrated due to practical constraints in experimental setups. The teacher deliberately chose a cartoon representation in week four to make abstract scientific knowledge more comprehensible. Similarly, in week five, the integration of real-world news about element discoveries provided relevance and engagement. For the MIX 1 lesson plan, questioning, the elements of BRH and Brandon matrix are utilized. For the MIX 2 lesson plan, based on the science topic, they prefer questioning as the teaching strategy.

Teacher Leyla encountered different challenges in integrating the nature of science each week. In week one, abstract concepts such as the aims and values of science were difficult for students to grasp. Week two was initially challenging due to a lack of clear direction, but historical scientific examples provided inspiration. By week three, the difficulty lay in getting students to consciously recognize the scientific practices they were engaging in. Week four posed the challenge of differentiating between various types of scientific knowledge, as students struggled to distinguish laws, theories, and models. However, using accessible representations helped mitigate this issue. Despite these challenges, the teacher adapted and refined her approach, demonstrating growth in her pedagogical strategies. For the last two weeks, she did not encounter any problems

integrating NOS issues into the lesson plan because they decided the categories of NOS that they would teach.

The teacher's reflections indicate a progressive and adaptive approach to integrating the NOS into lesson plans. They demonstrated a strong ability to select appropriate instructional methods, address conceptual challenges, and engage in meaningful collaboration. Their experience underscores the significance of flexibility, reflective practice, and cooperative planning in effectively teaching the NOS.

Leyla's Group Discussions

Leyla had prior knowledge about some categories of RFN before the intervention and stated that she adopted a student-centered teaching approach. In the lesson plan development sessions, Leyla tried to generate her own NOS objectives considering the science topics. She sometimes benefited from the examples provided in the PD program and example lesson plans. She discussed with her group members how to integrate NOS objectives to enable students to be active in her lesson. For example, during the lesson planning session of the AV workshop, they tried to recall the AV category and discussed which NOS learning objective would be most relevant. They exchanged ideas about objectivity and critical thinking. As the process progressed and they began to plan the activities, they decided to focus on accuracy and experimental competence as:

> "Aylin: So, experimental competence, accuracy, critical thinking—these three are definite. I'm thinking, for example, if an activity is done after that movement and each group draws a conclusion and then discusses it, maybe critical thinking can come in there. Like trying to justify their claims with reasoning.
>
> Leyla: At least we're making the groups discuss. So, they're considering opposing ideas and trying to ensure the accuracy of their explanations based on some experimental aspect. Or they can check the formula from the beginning—whether it holds true. For instance, I see here that the sum of potential and kinetic energy equals mechanical energy." (Group discussions, AV workshop)

For the (2) selection of teaching methods, Teacher Leyla prioritizes actively engaging her students in the learning process and integrating NOS concepts into every aspect of her lesson plans. However, working in a public school with limited resources, she often faces challenges when implementing diverse teaching strategies. To overcome this, she encourages student participation through group discussions and simulations, which promote

active learning. Additionally, she aims to create PowerPoint presentations to enhance the structure and flow of her lessons.

When assessing NOS understanding, Leyla encounters difficulties in developing NOS-specific assessment tools due to resource constraints. She typically evaluates students' understanding of NOS objectives through question-and-answer sessions, which allow her to gauge their comprehension effectively. Occasionally, she uses example lesson plans to design assessments tailored to NOS, adapting these resources to meet her classroom needs.

4.2.1.5. Case 5 – Melisa's Teaching Planning. In this session, data sources such as individual interviews, lesson plans, teacher journals, and group discussions are analyzed to investigate how teacher Melisa incorporates NOS activities into her lesson plans while participating in the online reflective collaborative PD program, structured by the RFN framework. Teacher Melisa teaches 5th, 6th, and 7th grades at her school. Therefore, she collaborates with all teachers during lesson plan development sessions.

Melisa's Individual Interviews

Teacher Melisa had prior knowledge of the RFN framework. She emphasizes that even though she was familiar with some categories of NOS, her perception of NOS developed after participating in the PD program, enabling her to integrate NOS categories into her lesson plans more effectively. She has gained confidence in highlighting NOS concepts, such as scientific models, laws, and theories, even with younger students who were previously unfamiliar with these ideas. The teacher has shown a proactive attitude towards making NOS visible and relevant in her lessons, aiming to incorporate more visual and project-based activities to deepen student understanding. The PD program seems to have not only enriched her knowledge of NOS but also fostered a greater sense of structure in her lesson planning. The teacher mentions that this increased organization in lesson planning boosts her confidence in delivering content effectively. She recognizes the importance of reflecting on her own teaching process and refining it over time, further indicating the positive impact of the program on her professional development. She conveys her ideas in the following way:

> "It has greatly contributed to updating my existing knowledge. When I first learned about this approach, I started emphasizing it more in the classroom about 4-5 years ago. But now, with this fresh knowledge, I will likely have even more of an impulse to emphasize it and talk about it more in class. For example, even though my 5th graders didn't know much about scientific types of knowledge like models, laws, and theories, I have already introduced them to these concepts. Now, I tell them, 'You remember we talked about this,' whenever it's relevant. So, I plan to emphasize things we've discussed and think about how I can make this more visible in each class. For example, the BRH in scientific practices could be a meaningful visual for the students, or the social and institutional structures of science might be emphasized through project assignments. I believe my practices will reflect this more in the future. I think what I do most is question and answer. I often ask, 'Do scientists do this too? Do you think this is related? Is this how it is?' I will definitely continue with that, but I also aim to make more visible actions." (Melisa, post-interview)

Furthermore, the teacher believes that creating daily plans enhances lesson organization and efficiency, helping students feel more comfortable. By outlining key components such as the introduction, development, and conclusion, they can clarify how students will engage and what they are expected to learn. However, they also mention that drafting daily plans is time-consuming and necessitates collaboration, sharing various experiences. Additionally, they note that this process will result in a stronger emphasis on assessing whether students have fully understood the material. She presents her ideas in this manner:

> "Daily planning has made things more practical and comfortable. While I might not always stick 100% to the plan, I'll focus on key elements like the introduction, development, and conclusion. I'll ensure clear plans for how to start, what to focus on in the middle, and what I expect from students at the end. This process has created some anxiety about whether students grasp the material, but I plan to focus more on this in the future. Writing daily plans is still time-consuming and requires collaboration and sharing experiences. The easy part is identifying the achievement, which I do using applications. I think this process will become more systematic over time." (Melisa, post-interview)

Melisa's Lesson Plans

Melisa worked as a group with all teachers during the lesson planning sessions. Her and her group members' scores for each lesson plan, gathered from the Lesson Plan Assessment Rubric, are given in Table 4.37. The lesson plans are evaluated and summarized, considering the items in the Lesson Plan Assessment Rubric.

In the lesson plan about AV of RFN, teacher Melisa collaborates with teacher Deniz. They selected a 7th grade science topic for the unit on Force and Energy. The evaluation of the lesson plan is provided under the title of Deniz's lesson plans.

The lesson plan for the M category of RFN is prepared by teacher Beren. They chose a 5th-grade science topic on friction. The evaluation of the lesson plan is presented under the title of Beren's lesson plans.

Table 4.37. Melisa's lesson score for each lesson plan.

Group members with Melisa	**Den.**	**Ber.**	**Zey.**	**Ber.**	**Ayl.**	**Zey.**	**Den.**
Item of assessment rubric/LP	LP1 (AV)	LP2 (M)	LP3 (SP)	LP4 (SK)	LP5 (SI)	LP 6 (MIX1)	LP 7 (MIX2)
The lesson plan explicitly states MoE learning objectives.	3	3	3	3	2	3	3
The lesson plan explicitly states RFN learning objectives.	3	3	3	3	3	3	3
All stated RFN objectives are covered in the lesson plan / all taught RFN objectives are explicitly listed in the RFN objectives list.	2	3	3	3	2	1	3
The lesson plan clearly describes prior knowledge of the students.	3	3	3	3	3	3	3
The lesson plan clearly describes procedures.	3	3	3	3	3	2	3
The activity in integrating of RFN category to the scientific topic is appropriate.	3	3	3	3	3	3	3
The RFN category is referred at least two parts of the lesson plan.	3	1	3	3	3	3	3
The lesson plan includes variety of resources/materials integrating technology.	3	3	3	3	3	3	3
The lesson plan promotes active engagement of students.	3	2	3	2	2	3	3
The lesson plan includes a variety of instructional techniques.	3	3	3	3	2	3	3
The lesson plan includes appropriate assessment methods.	3	2	3	3	2	3	3
RFN objectives are assessed during the assessment part of the lesson.	2	1	3	3	3	2	3
The lesson plan is instructionally appropriate in terms of time management.	3	3	3	3	3	3	3
Total Score:	37	33	39	38	34	35	39

For the SP category of RFN, teacher Melisa works with teacher Zeynep. They work on the 6th-grade science unit "Matter and Heat." Their MoE objective is "Students will be able to state that substances have a particulate, porous, and dynamic structure (The concepts of vibration, translation, and rotation related to the dynamic structure are addressed)." and "Students will be able to compare the changes in the gaps between particles and the mobility of particles depending on the state change by conducting an experiment." The NOS objectives are "Students will be able to classify the substances around them based on their different and similar properties," "Students will be able to make predictions about the internal structure of matter," "Students will be able to create models based on their predictions and compare them with scientific models," "Students will be able to make inferences by observing both the substances around them and the models in the simulation," and "Students will be able to establish a connection between the scientific practices they used during the activities and the Benzene Ring Heuristics." In this lesson plan, students are expected to experience various scientific practices such as making predictions, classification, observation, and modeling. However, based on the lesson plan, it is clear that it does not explicitly emphasize why these practices are important in science or why scientists use them in their studies. In the introduction, the teacher asks about the characteristics of matter through brainstorming. In the development section, the teacher divides students into groups and distributes worksheets. In the worksheet, students classify different materials and do some practical activities using daily life examples to answer questions such as, "Which substance is the most and least compressible? Do you think there is a relationship between the states of matter and their compressibility?" Then, a simulation is opened on the smart board, and students make observations and answer the same questions about solid, liquid, and gas matter. In the results section, students respond to both science and NOS-based questions. BRH is used in the evaluation part of the lesson. Students are active in this lesson plan through group activities and diverse scientific practices. Different teaching materials are used, such as simulations and daily life materials. The duration is appropriate for implementation.

For the lesson plan SK of RFN, teacher Melisa works with teacher Beren. They selected a 5th-grade science unit, which is "Matter and Change." The evaluation of the lesson plan is provided under the title of Beren's lesson plans.

For the SI category of RFN, teacher Melisa collaborates with teacher Aylin. They select a 7th-grade science topic, which is pure substances and mixtures. The evaluation of the lesson plan is provided under the title of Aylin's lesson plans.

For the MIX1 category of RFN, teacher Melisa works with teacher Zeynep. They selected the 6th grade science unit on "Matter and Heat." The MoE objectives are: "Students will be able to define density," and "Students will be able to calculate the densities of various substances based on the experiments designed." The NOS objectives are: "Students will be able to explain different scientific methods (M)," "Students will be able to identify the variables to be used in their activities (M)," "Students will be able to determine the scientific methods they use in their activities (M)," "Students will be able to develop a testable hypothesis (M)," "Students will be able to provide examples of experimental and observational studies (M)," "Students will be able to categorize scientific activities as experiments, observations, and classifications (SP)," "Students will be able to establish a connection between the scientific practices they used during the activities and the Benzene Ring Heuristics (SP)," and "Students will be able to explain the benefits of scientific laws to humanity (SK)." It is noted that not all RFN objectives are taught in the lesson. Additionally, the objective in the scientific knowledge category of the lesson plan is actually related to the aims and values of science, but teachers label it as scientific knowledge. In the engagement part of the lesson plan, students watch a video about Archimedes and his Buoyancy Law. While watching the video, the teacher asks some questions about scientific methods and practices. In the development part of the lesson, students are shown a simulation and are asked to test their hypotheses by selecting materials based on their volume and mass. They are expected to write their observations on their worksheets. In the results part of the lesson plan, a whole group discussion is held. Students discuss the results of the simulations and the practices they experienced through Benzene Ring Heuristics. Students are active through questions, answers, and simulations. The procedure of the lesson is not very clear regarding whether there is a group activity or not. Also, the activity sheet is incomplete. They use different teaching strategies and materials. The duration is sufficient for the implementation.

For the MIX 2 lesson plan, teacher Melisa works with teacher Deniz on a 7th grade science topic. She continues with the same unit, "Pure Substances and Mixtures." The evaluation of the lesson plan is provided under the title of Deniz's lesson plans.

Melisa's Journals

For the first question, Teacher Melisa reflects on her experiences integrating NOS into her lesson plans. Analysis of the seven-week teacher journals indicated that teacher Melisa incorporated NOS activities into lesson plans to a more structured and effective approach. For the AV category of RFN, they make explicit verbal connections to NOS; for the M category of RFN, they incorporate experimentation; for the SP category of RFN, they focus on observation and classification; for the SK category of RFN, they use didactic teaching; and for the SI of science, they use news and questioning. In the MIX1 lesson plan, her group selects the SP, M, and SK categories of NOS, and for the final MIX2 lesson plan, they select the SP and SI categories of RFN. They chose these categories because the science content is suitable for conducting experiments and engaging in practical experiences. In the final weeks, teachers have the flexibility to select multiple NOS components, leading to creative lesson plans that combine historical narratives and online experiments. Teacher Melisa expresses the teaching strategies they select for the lesson plan in week 5 as:

> "I think we were inspired by the news activity we did in the workshop. :) We believed that discussing a real event covered in the media would make the connections to the relevant theme clearer. We aimed to reinforce these connections through the questions on the activity sheet and class discussions. My students already had some prior knowledge about CERN, but we had not discussed aspects such as Türkiye's membership, financial commitments, and how this topic was addressed in the parliament. With the questions we posed, we aimed to open a discussion on the importance of international collaboration, the transfer of scientific findings to different fields, the relationship between science and the economy, the role of governments in scientific research." (Melisa, teacher journal, week 5)

In her journals, Teacher Melisa reflects that the selection of teaching strategies is primarily influenced by the lesson objectives, students' prior knowledge, and classroom constraints. In Week 2, for example, a demonstration experiment is chosen over hands-on experimentation because students are unfamiliar with manipulating variables, and classroom size limited individual engagement. By contrast, in Week 4, when introducing types of scientific knowledge, a didactic approach is used alongside a video that explains the differences between theories and laws, as this method is more effective in clarifying abstract concepts. In Week 5, real-world news articles are incorporated to contextualize the societal impact of scientific discoveries and encourage discussions about how scientific research is influenced by politics and the economy. By Week 6, a combination of question-and-answer sessions, historical storytelling, and online simulations is employed to cater to different

learning styles. These choices reflect a strategic balance between content complexity, student engagement, and available resources.

Teacher Melisa believes she struggles to integrate NOS explicitly while maintaining a focus on content knowledge. In Week 1, for instance, she found herself designing lessons that were 85% content-based and only 15% focused on NOS elements. For her, adjustments are needed to ensure students can actively recognize the AV of science rather than just hear about it. In Week 2, difficulties arose when attempting to implement the scientific method due to students' unfamiliarity with variables, leading to a reliance on demonstration rather than hands-on activities. In Week 4, linking phase changes to different types of scientific knowledge (e.g., theories vs. laws) proves challenging, requiring additional explanatory support through videos. By the final weeks, the main challenge shifted to time management. While teachers gained confidence in integrating NOS, the limited lesson duration prevents deeper exploration of some topics, such as modeling and prediction in Week 7. In the final two weeks, she does not struggle to integrate NOS into lesson plans.

Melisa's Group Discussions

When group discussions were analyzed, it was found that Teacher Melisa selected NOS objectives primarily based on the science topic being taught. She focused on creating strong connections between NOS concepts and the science content to enhance student understanding. Additionally, she collaborated closely with her group members to reach a consensus while developing lesson plans, ensuring alignment with educational goals. Over the weeks, the integration of NOS concepts into each component of her lesson plans became more consistent and intentional. Melisa and her group occasionally drew inspiration from objectives outlined in the PD program and adapted example lesson plans to fit their classroom needs.

For (2) the selection of activities and teaching methods, Melisa prioritized actively engaging her students through class discussions, which encouraged critical thinking and participation. Due to her large class size, she generally avoided group activities as they were challenging to manage effectively in terms of time. During group discussions with colleagues, she shared insights from her visit to CERN, which inspired her to design lesson

plans incorporating real-world scientific institutions like CERN. In her lesson plans, she emphasized writing clear and detailed procedures to ensure students could easily follow activities and achieve learning objectives. For example, for the lesson planning session of the SI category, Melisa discussed with her group member how to incorporate NOS into their lesson plan as:

> "Aylin: So… let me put it this way. Students will be asked to read the news article on the second page of the worksheet. Based on this article, could we ask something like: "What can be said about Turkey's support for scientific research?"
>
> Melisa: Then, depending on the answers, a follow-up question could be: "What kind of policies can governments adopt to support scientific development? Why does scientific research require international collaboration? Why are international research centers like CERN important? That could be a question, too. Then we could ask: "Why is Turkey's associate membership in CERN important in terms of opportunities for Turkish scientists?" (group discussions, SI workshop)

For (3) the assessment of NOS, Melisa employed varied methods to evaluate students' understanding. She frequently used question-and-answer sessions to gauge comprehension in real time, fostering interactive dialogue. Additionally, she occasionally distributed worksheets with targeted questions about NOS concepts, providing a structured way to assess students' understanding of the material and identify areas for improvement.

4.2.1.6. Case 6 – Zeynep's Teaching Planning. In this session, data sources such as individual interviews, lesson plans, teacher journals, and group discussions are analyzed to investigate how teacher Zeynep incorporates NOS activities into her lesson plans while participating in the online reflective collaborative professional development program structured by the RFN framework. In her school, teacher Zeynep works with 5th and 6th graders. Therefore, she collaborated with teachers Aylin, Beren, Leyla, and Melisa during lesson plan development sessions.

Zeynep's Individual Interviews

Teacher Zeynep highlights significant growth in her approach to lesson planning and the integration of NOS. She acknowledges that the PD program has provided valuable insights, particularly in incorporating NOS into her lesson plans, which was previously not a focal point. She also emphasizes the positive impact of collaborating with other teachers to develop lesson plans during the PD program. Additionally, she found opportunities to

exchange perspectives, effective teaching strategies, and experiences. She presents her ideas as follows:

> "I definitely plan to integrate this into my lessons. In fact, we had a meeting with the entire department yesterday about how we can integrate the NOS and how it can contribute to our future lesson structures. I believe this PD program has helped me improve, especially in lesson planning. I had prepared lesson plans before, but I didn't have a specific focus on integrating the NOS. I gained experience through this process, and it has been very beneficial to me. Additionally, I got to meet different teachers, saw their perspectives, and benefited from their knowledge. These two months have been productive for me. In future lessons, I plan to emphasize NOS as well. Our school already has a system in place where we continuously prepare lesson plans. Now, when preparing lesson plans, I have a clearer idea in my mind about which aspects of the NOS I need to include. I have realized how necessary this is." (Zeynep, post-interview)

Additionally, she expresses confidence in applying her newly gained knowledge to future lessons at her school. She is already discussing teaching NOS in her department for upcoming lessons. It can be said that the PD program appears to have fostered both personal and professional growth, leading to more thoughtful and systematic lesson planning.

Zeynep's Lesson Plans

Zeynep worked as a group with all teachers during the lesson planning sessions. Her and her group members' scores for each lesson plan, gathered from the Lesson Plan Assessment Rubric, are given in Table 4.38. The lesson plans are evaluated and summarized according to the items in the Lesson Plan Assessment Rubric.

For the lesson plan about the AV category of RFN, teacher Zeynep collaborates with Beren Teacher. They select a 5th-grade science topic on Measurement of Force and Friction Force. The evaluation of the lesson plan is provided under the title of Beren's lesson plans.

For the lesson plan in the M category of RFN, teacher Zeynep collaborates with teacher Aylin for the 6th-grade topic of Force and Movement. The evaluation of the lesson plan is provided under the title of Aylin's lesson plans.

For the SP category of RFN, teacher Zeynep collaborates with teacher Melisa. They focus on the 6th-grade science unit of "Matter and Heat." The evaluation of the lesson plan is provided under the title of Melisa's lesson plans.

For the lesson plan SK, Teacher Zeynep collaborates with Teacher Leyla. They selected the 5th-grade science topic of Heat Transfer. The evaluation of the lesson plan is provided under the title Leyla's lesson plans.

Table 4.38. Zeynep's lesson score for each lesson plan.

Group members with Zeynep	**Ber.**	**Ayl.**	**Mel.**	**Ley.**	**Ber.**	**Mel.**	**Ber.**
Item of assessment rubric/LP	LP1 (AV)	LP2 (M)	LP3 (SP)	LP4 (SK)	LP5 (SI)	LP 6 (MIX1)	LP 7 (MIX2)
The lesson plan explicitly states MoE learning objectives.	3	3	3	3	3	3	3
The lesson plan explicitly states RFN learning objectives.	3	2	3	3	3	3	3
All stated RFN objectives are covered in the lesson plan / all taught RFN objectives are explicitly listed in the RFN objectives list.	3	2	3	3	3	1	3
The lesson plan clearly describes prior knowledge of the students.	3	3	3	3	3	3	3
The lesson plan clearly describes procedures.	3	2	3	3	3	2	2
The activity in integrating of RFN category to the scientific topic is appropriate.	3	3	3	3	3	3	3
The RFN category is referred at least two parts of the lesson plan.	2	3	3	3	3	3	3
The lesson plan includes variety of resources/materials integrating technology.	3	3	3	3	3	3	3
The lesson plan promotes active engagement of students. (Group activity: 3; QA: 2)	3	3	3	2	2	2	2
The lesson plan includes a variety of instructional techniques.	3	3	3	3	2	3	3
The lesson plan includes appropriate assessment methods.	2	2	3	3	3	3	3
RFN objectives are assessed during the assessment part of the lesson.	1	2	3	3	3	2	3
The lesson plan is instructionally appropriate in terms of time management.	3	3	3	3	3	3	2
Total Score:	35	34	39	38	37	34	36

For the lesson plan SI, teacher Zeynep collaborates with teacher Beren on the 5th-grade science topic of the melting, freezing, and boiling points of pure substances. The evaluation of the lesson plan is provided under the title of Beren's lesson plans.

For the MIX1 category of RFN, teacher Zeynep works with teacher Melisa. They selected the 6th-grade science unit on “Matter and Heat.” The evaluation of the lesson plan is provided under the title of Melisa’s lesson plans.

For the final lesson plan of MIX2, teacher Zeynep collaborates again with teacher Beren. They chose the 5th-grade science topics of the expansion and contraction of substances due to heat. The evaluation of the lesson plan is provided under the title of Beren’s lesson plans.

Zeynep’s Journals

Throughout the seven weeks, teacher Zeynep employed diverse strategies to integrate the NOS into their lesson plans. In the first week, they focused on hands-on learning, ensuring that students actively engaged in scientific discovery by conducting experiments and making observations, which fostered an inquiry-based approach. For example, they designed activities where students simulated the work of scientists to uncover information rather than receiving direct instruction. In week two, scientific methods were emphasized through problem-solving exercises that required students to manipulate variables and analyze graphical data. A notable example was guiding students to design their own experiments with manipulated variables, reinforcing their understanding of data interpretation. Similarly, in week three, scientific practices were incorporated by having students classify and model real-life examples, such as the compressibility of solid, liquid, and gas materials, effectively linking theoretical knowledge with tangible experiences. By week four, teachers shifted their focus to scientific knowledge, utilizing discussion-based strategies to highlight the distinctions between laws, theories, and models. This allowed students to develop their analytical skills and address misconceptions through structured debates. In week five, the social-institutional aspects of science were explored by having students investigate how scientists contribute to knowledge dissemination, prompting them to consider multiple perspectives through problem-solving discussions. During the final two weeks, teachers had the flexibility to integrate multiple aspects of the NOS into their lesson plans. For instance, in week six, they utilized videos and simulation, such as Archimedes’ ship, to help students understand scientific methodology and the importance of repeated testing. In week seven, they expanded this approach by integrating hypothesis formulation

and classification tasks, encouraging students to think critically and compare their ideas with established scientific principles. She reflects her ideas about the selection of teaching strategies for week 5 as:

> "We researched the relevant laws, theories, and models that we can use in our lessons and integrated them with the aim of creating discussions where students predict and explore their differences and interactions without directly explaining the details of these laws and theories. Since each student may have a different perspective on this topic, we chose the discussion method to identify possible misconceptions." (Zeynep, teacher journal, week 4)

Teacher Zeynep faced various challenges depending on the topic. In the first week, some students struggled with unfamiliarity with scientific terminology, making it difficult for them to connect their experimental activities to conceptual frameworks. Similarly, in week four, explaining the differences between scientific laws and theories in a simplified way was challenging, as the abstract nature of these concepts required extensive scaffolding. In week five, finding relevant real-world examples and news articles related to the social and institutional aspects of science proved difficult, limiting opportunities for direct application. Additionally, while problem-based learning was effective, some teachers noted that time constraints hindered deeper exploration of complex issues. Despite these challenges, Zeynep found collaboration with peers beneficial in refining lesson plans. For example, in week two, time management was an issue, but structured group work allowed for more efficient lesson planning. In the final weeks, the flexibility to choose multiple aspects of the nature of science made integration easier, as teachers could tailor activities to student engagement levels. However, achieving consensus on shared lesson activities remained challenging when working in groups.

Overall, while integrating the NOS into lesson plans required thoughtful adaptation to students' needs, teachers successfully employed various instructional strategies to enhance scientific thinking and engagement in their classrooms.

Zeynep's Group Discussions

In (1) the selection of NOS objectives, Teacher Zeynep relied heavily on the example lesson plans provided in the PD program. Since she works in a private school with a structured lesson plan framework, she prioritized adapting NOS objectives to align with her

school's curriculum. This approach enabled her to seamlessly integrate NOS concepts into her science lessons while adhering to institutional expectations.

For the selection of activities and teaching practices, group discussions during the second session of the PD workshops revealed that Zeynep was highly experienced in using group activities to teach science. She preferred incorporating group work into her lesson plans to foster collaboration and active learning among her students. Zeynep's familiarity with a variety of activities enabled her to lead her group in selecting engaging tasks. To meet the needs of both teachers' classrooms, they adapted their activities to be flexible, ensuring effectiveness for teaching groups of varying sizes. For example, for the lesson planning session of the M category, she suggested to use her previous activities for the issue of velocity as:

> "Zeynep: For example, in the past, I used to take them out to the schoolyard and have them run from one end to the other. I would time them. Let's say one student ran it in one minute and another in two minutes. They ran the same distance. Then I'd lead a discussion about that. Something similar could be done again.
>
> Aylin: Also, since I only have one class period, taking them outside and bringing them back in might be a bit much.
>
> Zeynep: Why? Why shouldn't it be possible? They might struggle a bit with drawing graphs, maybe.
>
> Aylin: Since I only have a single class period, taking them out and then back in could be a bit difficult." (Group discussions, week 2)

Regarding the assessment of NOS, Zeynep and her group member employed multiple strategies to evaluate students' understanding of NOS objectives. They frequently used the question-and-answer method to encourage critical thinking and assess comprehension of NOS. Additionally, they incorporated visuals and tables, inspired by the example lesson plans, to create engaging and structured assessments that helped students demonstrate their understanding of NOS concepts more effectively.

4.1.2.7. Summary of the Teaching Planning of the Cases. Teacher Aylin collaborated with all teachers to develop lesson plans for 5th–7th graders, focusing on integrating the NOS through the RFN framework over seven weeks. She favored inquiry-based teaching methods, employing strategies like brainstorming, large group discussions, and experiment

observation activities to actively engage students, as seen in her journals (e.g., AV via critical thinking questions, SI through CERN references, SP via experiential practices). Her NOS integration was evident but often concentrated in the assessment sections rather than throughout the lesson, as reflected in her lesson plan scores (e.g., LP1, LP3: Rubric Item 7). Aylin's plans consistently received high scores on technology integration and time management (Items 8, 13), ensuring resources like videos and visuals were utilized, although active student engagement varied (Item 9), reflecting limited group activities in some plans. She faced challenges such as concept confusion, particularly in Week 7 when distinguishing elements and compounds, and time management issues, which she addressed by revising activities to clarify concepts and adding explanatory examples to align with NOS objectives, demonstrating adaptability and growth in her lesson planning process.

Teacher Beren collaborated with Aylin, Leyla, Melisa, and Zeynep to develop lesson plans for 5th graders, emphasizing NOS integration over seven weeks. She favored interactive teaching methods, including questioning, videos, and simulations, to promote inquiry-based learning (e.g., SK via TLM visuals, SI using EBA interactive videos, AV through questioning like "If you were a scientist, what would you investigate?"). Her lesson plans demonstrated consistent NOS integration in some cases (e.g., LP4, LP5: Item 7) but others lacked depth (e.g., LP2: Item 7—scored 1). Beren's plans excelled in outlining prior knowledge and procedures (Items 4, 5), ensuring clarity, although group activities were limited (Item 9). Her journals reveal challenges, including formulating in-depth AV questions (Week 1), selecting suitable assessment tools for SP (Week 3), and connecting phase changes to SK (Week 4), which she addressed by utilizing PD example lesson plans and refining her assessment strategies to better align with NOS objectives, enhancing her instructional approach.

Teacher Deniz collaborated with Aylin, Leyla, and Melisa to develop lesson plans for 7th graders, emphasizing NOS integration through the RFN framework. She implemented interactive, inquiry-based methods such as simulations, questioning, and the Benzene Ring Heuristics (BRH) to engage students (e.g., AV via simulations, M using Brandon's Matrix, SI through CERN texts). Her lesson plans exhibited strong NOS integration across multiple sections (e.g., LP2, LP4: Item 7), although some showed inconsistency (e.g., LP3, LP5: Item 7). Deniz's plans received high marks on procedures and

assessment methods (Items 5, 11), facilitating active engagement through group activities and question-answer sessions (Item 9). Technology integration was robust (Item 8: 3s), using tools like EBA videos. Journals reflect challenges such as aligning AV assessments (Week 1), sourcing SI materials (Week 5), and addressing student unfamiliarity with variables (Week 2), which she addressed through peer collaboration, adapting strategies (e.g., using simulations instead of hands-on experiments), and refining lesson plans to balance NOS and content objectives, fostering a more student-centered approach.

Teacher Leyla collaborated with all teachers to develop lesson plans for 5th–7th graders, integrating NOS over seven weeks. She utilized student-centered methods such as classification exercises, real-life applications, and discussions (e.g., SK via cartoons, SI through element naming discussions, SP via classification tasks), aiming to make NOS accessible. Her lesson plans demonstrated varied NOS integration (e.g., LP2, LP4: Item 7; LP1, LP5), reflecting an inconsistent distribution across sections. Leyla's plans performed well in prior knowledge and instructional techniques (Items 4), employing diverse strategies like BRH and real-world examples; however, student engagement was mixed (Item 9). Technology use was strong (Item 8), incorporating visuals and presentations. Journals reveal challenges with abstract AV concepts (Week 1), student recognition of SP (Week 3), and SK differentiation (Week 4), which she addressed by using simplified representations (e.g., cartoons) and peer feedback, enhancing her structured, inquiry-focused approach.

Teacher Melisa worked with all teachers on lesson plans for 5th to 7th grades, refining her NOS integration skills. She employed a combination of experimentation, direct teaching, and discussions (e.g., M through experiments, SI via news articles, SP using simulations), balancing inquiry with direct instruction to accommodate diverse learners. Her lesson plans demonstrated consistent NOS integration (e.g., LP3, LP5: Item 7), although some lacked depth (e.g., LP6). The use of technology was strong (Item 8: 3s), incorporating tools like EBA simulations, and assessment methods were effective (Item 11: mostly 3s), though engagement levels varied (Item 9). Journals highlight challenges in balancing content with NOS (Week 1), executing hands-on experiments (Week 2), and time management (Week 7), which she addressed by refining her strategies (e.g., using simulations, discussions) and drawing on peer insights to ensure clearer procedures (Item 5) and structured lesson plans.

Teacher Zeynep collaborated with Aylin, Beren, Leyla, and Melisa to develop 5th–6th-grade lesson plans, enhancing her NOS integration. She favored inquiry-based methods such as hands-on experiments, discussions, and simulations (e.g., AV via experiments, SK through debates, SI using news articles), encouraging active learning. Her lesson plans demonstrated strong NOS integration across phases (e.g., LP3, LP5: Item 7), although some lacked consistent assessment (e.g., LP1: Item 12). Technology integration was robust (Item 8), utilizing videos and simulations, and instructional techniques were diverse (Item 10), although engagement varied (Item 9). Journals indicate challenges with student terminology (Week 1), SK abstraction (Week 4), and time constraints (Week 5), which she addressed through historical narratives, simulations, and peer collaboration, fostering creative, student-centered lesson plans that aligned with NOS objectives.

Additionally, teachers are compared considering the incorporation of NOS-based activities into their lesson planning. Table 4.39 presents a summary of the codes obtained from diverse data sources, which are individual interviews, lesson plans, teacher journals, and group discussions.

Teachers show both similarities and differences in how they incorporated NOS activities and content into their lesson plans based on their pre- and post-interviews. For example, teachers Aylin, Leyla, and Deniz all mention the use of NOS questions, showing that they consciously embedded NOS into classroom dialogue. Similarly, Beren and Deniz highlight inquiry-based questioning, and Leyla and Deniz emphasize fostering curiosity and student engagement, which are aligned with NOS-focused instructional approaches. These practices indicate that the PD program was effective in promoting an inquiry-oriented understanding of NOS. Moreover, teachers Aylin, Beren, and Melisa referenced the benefit of PD presentations and sample plans, suggesting that these resources were instrumental in shaping their instructional designs. Leyla and Melisa also pointed out the importance of structured lesson planning, reinforcing the idea that PD helped them move from abstract NOS concepts to concrete classroom practices.

However, there are also notable differences. For instance, while teachers Aylin and Beren focused on the historical and philosophical aspects of science, such as History of Science (HOS) examples and acknowledging subjectivity in science, Melisa and Zeynep leaned more toward practical instructional strategies like project-based learning, use of

models, and collaboration in lesson planning. Zeynep, in particular, did not mention NOS questions directly but emphasized teacher collaboration and effective strategies, suggesting a broader pedagogical focus rather than a NOS-specific one.

Considering the teacher journal data source, six cases are compared and contrasted based on three main themes, which are the integration of NOS into the lesson plan, determining strategy, and difficulties. In terms of the integration of NOS into lesson plans, all six teachers consistently used questioning as a central approach to foster critical thinking and inquiry. Similarly, experiencing scientific practices (SPs) and discussions were widely implemented, suggesting a shared understanding of how to make NOS visible in classroom practice. Many teachers, including Aylin, Deniz, Leyla, and Zeynep, also used tools like videos, simulations, and real-life connections (e.g., CERN, news articles) to contextualize NOS concepts. However, differences emerge in the variety and depth of methods. Beren and Leyla, for example, employed more diverse strategies such as the Brandon Matrix, cartoon representations, and historical case studies, while Aylin and Zeynep used more traditional techniques like classical teaching methods and hands-on activities. For the theme of determining strategy, a strong similarity is the emphasis on student engagement, which was prioritized by almost all teachers. This indicates a common shift toward student-centered learning influenced by the PD. Several teachers, including Aylin, Deniz, and Melisa, also cited the science topic as a key factor in their planning. Meanwhile, others, such as Beren and Leyla, noted the availability of resources and students' prior knowledge as influential elements. Zeynep uniquely emphasized using a variety of strategies, reflecting a flexible and adaptive planning approach. When it comes to difficulties, the most frequently reported issues were time management and resource limitations, mentioned by Aylin, Deniz, Leyla, and Zeynep. Additionally, many teachers, including Beren, Leyla, and Melisa, expressed challenges in distinguishing different types of SK a recurring conceptual difficulty. Some teachers also faced more specific obstacles: Beren had trouble with assessment tools and making connections between NOS and science content in the early weeks; Melisa struggled to find relevant NOS examples, and Leyla noted the challenge of making abstract concepts more concrete. Zeynep mentioned classroom size as a constraint, pointing to contextual variability.

Based on the lesson plan assessment rubric results, all teacher groups received high scores, indicating successful integration of the RFN objectives. However, there were notable differences in their low-scored items. While Aylin and Melisa's groups struggled with explicitly listing RFN objectives and ensuring they appeared in at least two parts of the plan, Beren, Deniz, and Zeynep's groups had lower scores in actively engaging students and assessing RFN objectives during the lesson. Leyla's group differed slightly by scoring low on clearly describing procedures. These variations suggest that although the overall quality of plans was strong, each group faced specific challenges in aligning NOS content with pedagogy and assessment.

During the group lesson planning process, teachers demonstrated both commonalities and distinctions in how they approached the integration of NOS based on group discussions. Aylin focused on selecting objectives aligned with aspects such as AV, SP, and SI, relying heavily on structured activities and sample lesson plans, and using Q&A for assessment. Similarly, Beren emphasized AV, M, and SK categories, also benefiting significantly from example lesson plans. In contrast, Deniz considered more contextual factors like classroom conditions and student profiles, drawing NOS objectives from PD resources but preferring whole-class strategies over small-group work. Leyla showed a more integrative approach by generating NOS objectives aligned directly with science topics and prioritizing active student engagement, although she only occasionally used PD resources. Melisa distinguished herself by fostering critical thinking through class discussions and applying varied assessment strategies, building on her experience from a CERN visit. Lastly, Zeynep displayed the strongest reliance on PD sample plans and worked to align NOS objectives with her private school's curriculum.

Table 4.39. The codes of teachers' incorporation of NOS-based activities into the

Data Sources	Aylin	Beren	Deniz	Leyla	
Individual interview	Use of NOS questions Real-life connections HOS (History of Science) examples Pre-planned questioning and examples Encouraging deeper inquiry Benefit from PD presentations and sample plans	Encourage scientific thinking Inquiry-based questioning HOS examples Emphasis on SK development Acknowledge subjectivity in science Benefit from PD presentations and sample plans	Promote active participation Foster curiosity Use of discussions and experiments Inquiry-based questioning Use of videos and articles Conduct activities Include NOS question	Use of NOS questions Link NOS to science content Foster curiosity and engagement Structured lesson planning Encourage active participation Focus on assessment and reflection	Use of n projects Structur planning Promote centered Set clear Need for in LP de Benefit presenta sample p
Lesson plans	Taking good scores from the lesson plan assesment rubric. **Low scored items:** All stated RFN objectives are covered in the lesson plan/ all taught RFN objectives are explicitly listed in the RFN objectives list. The RFN category is referred at least two parts of the lesson plan. The lesson plan promotes active engagaement of students.	Taking good scores from the lesson plan assesment rubric. **Low scored items:** The lesson plan promotes active engagaement of students. RFN objectives are assessed during the assessment part of the lesson.	Taking good scores from the lesson plan assesment rubric. **Low scored items:** The RFN category is referred at least two parts of the lesson plan. The lesson plan promotes active engagaement of students.	Taking good scores from the lesson plan assesment rubric. **Low scored items:** The RFN category is referred at least two parts of the lesson plan. The lesson plan promotes active engagaement of students. RFN objectives are assessed during the assessment part of the lesson.	Taking g from the assesme **Low sco** All state objectiv in the le taught R are expl the RFN list. The less promote engagae students

Table 4.39. The codes of teachers' incorporation of NOS-based activities into their le

Data Sources	Aylin	Beren	Deniz	Leyla	
Teacher journal	**Integration of NOS into LP** Questioning Critical thinking Experiencing SPs Making connection to CERN **Determining strategy** Active student participation Science topic **Difficulties** Time management Resource limitations Concept confusions	**Integration of NOS into LP** Questioning Experiencing SPs Discussions Modelling Watching video Classical teaching methods Hands-on experiments Historical case studies Real-world examples Using simulations **Determining strategy** Student engagement Availability of resources **Difficulties** Not asking in depts questions about AV Finding appropriate assessment tools Making connection between the science topic and NOS for the first five weeks	**Integration of NOS into LP** Questioning Simulation Classical teaching techniques Using Brandon matrix Giving examples from the HOS Using BRH Using news Incorporating technology Discussions Brainstorming **Determining strategy** Science topic Student engagement Availability of resources Time management **Difficulties** Assesment tools for RFN Differentiation from prior plans Resource limitations	**Integration of NOS into LP** Group work Using Brandon Matrix Experiencing SPs Real-life examples Providing examples of different kinds of SK Discussions Using cartoon representation Real-world examples **Determining strategy** Student engagement Availability of resources **Difficulties** Making abstract concepts concrete Distinguishing types of SK	**Integrat** **into LP** Questio Verbal c NOS Experim Experie Classica techniqu Using n Historic Simulati Making CERN Watchin **Determ** Science Students knowled Availabi resource **Difficul** Classroo Distingu of SK Time ma

Table 4.39. The codes of teachers' incorporation of NOS-based activities into their le

Data Sources	Aylin	Beren	Deniz	Leyla	
Group discussions	Selects objectives for AV, SP, SI Relies on sample lesson plans Assesses NOS via Q&A Structured school activities support NOS integration	Focus on AV, M, SK categories High benefit from example lesson plans	Considers classroom conditions and student profiles Uses NOS objectives from PD materials Prefers whole-class over small group work Faces challenges with NOS assessment tools	Generates NOS objectives aligned with science topics Occasionally uses PD resources and sample plans Prioritizes active student engagement and NOS integration LP	Uses cla to promo thinking Shared e from CE Applies assessm

4.2.2. Results of Incorporating NOS Activities into Their Teaching Practices

In this section, it is aimed to present the findings of the second sub-research question, which is "RQ2.2. How do science teachers integrate NOS-based activities into their classroom practices after completing the RFN-based online reflective and collaborative PD program?" Each week, workshops focus on different categories of RFN. During the first session of the workshop, teachers learn about one of the categories of RFN through group activities and examine example lesson plans. In the second session of the workshop, teachers prepare lesson plans considering the relevant RFN category, their students' levels, and the science topics they must follow in their schools for the first five weeks of the workshop. They implement their lesson plans in their schools after the second session and then share their experiences in the third session. For the last two weeks, teachers have prepared their lesson plans in groups, integrating at least two RFN categories they wish to consider based on the science topic they have to follow. The researcher observes each participant twice during the final two weeks. To investigate how science teachers incorporate NOS activities into their teaching practices, four data sources are used: individual interviews, teacher journals, observation forms, and group discussions conducted in the third session of each workshop.

For the individual interview, teachers are asked, "How do you see yourself in teaching NOS in your lessons?" during their pre-interviews. They are also asked the questions, "Do you think NOS should be taught in science lessons? Why? How much do you think NOS categories are integrated into science lessons? Do you think it is possible to teach NOS categories in a science lesson? What do you think about the effects of the PD program on your classroom practices? How would you evaluate your science teaching after the PD program?" and "How do you see yourself in teaching NOS in your lessons after the PD program?" in their post-interviews. Each question is analyzed through open coding, with related themes and quotations provided for each case separately.

The researcher visited each teacher twice to observe the implementation of the last two lesson plans. She used an observation form and took notes on her observations. Table 4.40 indicates which lesson plans were observed by the researcher. The observation form consists of items related to teaching and reflection. The results will be presented based on

the scores collected from the observation form and the notes taken by the researcher during the observation.

Table 4.40. Observed teaching practice by the researcher.

	MIX1 lesson plan		**MIX2 lesson plan**	
Group 1	Aylin	Beren	Beren	Zeynep
Group 2	Melisa	Zeynep	Aylin	Leyla
Group 3	Deniz	Leyla	Deniz	Melisa

The teachers answered the questions in their journals. Some of the questions in their journals pertained to their implementations of lesson plans. The questions are: “What did go well with the lesson? Was there anything unexpected during the instruction? Would you like to change anything about the activities if you were doing them for a second time? Do you think the students were able to reach their learning goals? How do you know? Do you think the lesson was meaningful for them? Why do you think so?” and “Could you evaluate your teaching practice considering the weekly RFN category?” Teachers reflected on their experiences in their journals for seven weeks. In analyzing this data source, the reflections from those seven weeks are summarized for each case, and general findings are presented. Quotations are provided for each case.

Finally, teachers’ group discussions were analyzed to investigate how teachers incorporate NOS activities into their teaching practices. After implementing their lesson plans, teachers shared their experiences in the third session of the workshops. They considered the question they were directed to as they shared. Since the members of the same group implemented the same lesson plan in their classrooms, the questions aimed to determine (1) the evaluation of their lesson plans; (2) the similarities and differences in their experiences during implementation; and (3) suggestions for improving the lesson plan and its implementation. The questions are (1) “Did you have difficulty integrating the related RFN category into your lesson plans? Was your lesson plan feasible to implement? What do you think are the strengths and weaknesses of your lesson plan?”, (2) “What went well during your classroom implementation? What challenges did you face during your classroom implementation? Do you think students were able to achieve the learning objectives? Do you

believe the lesson was meaningful for the students? What were the common and different experiences you encountered while implementing the same lesson plan? What could be the reason for these differences?" and (3) "If you were to implement the same classroom practice again, would you make any changes to this lesson plan?" Teachers' experiences were determined based on the answers they provided to these questions during the third session of the workshops. The findings are presented for each case separately. Finally, for each data source, teachers' incorporation of NOS activities into their teaching practices is assessed,

4.2.2.1. Case 1 – Aylin's Teaching Practice. To investigate how teacher Aylin translated her NOS understanding into teaching practice, four data sources which are individual interviews, teacher journals, observation forms, and group discussions from the reflection and discussion sessions of workshops were analyzed separately.

Aylin's Interviews

Before the intervention, teacher Aylin is asked the question, "How do you see yourself in teaching the NOS in your lessons?" She feels inadequate regarding both her knowledge and teaching practice of NOS. She needs to see more examples of how to teach NOS, utilize materials for teaching NOS, and gain more confidence in her NOS knowledge. She expresses her ideas as:

> "I see myself as inadequate. I wish I could do more. Since I lack knowledge, I tend to hold back a bit to avoid teaching something incorrectly, but I do try to provide examples. I need more information. That's why I accepted you right away. I need both more knowledge and more examples. I keep giving the same specific examples every year, in the same places, over four years. But I wish I could also give examples for diverse science issues. That's why I want to diversify myself." (Aylin, pre-interview)

After participating in the PD program, Teacher Aylin was asked the question, "In this PD program, you developed lesson plans and implemented them in your classrooms during those weeks. At this point, how was your experience with the implementation?" Teacher Aylin believes that through this program, she became familiar with NOS, and it served as a warm-up activity in terms of practice. She thinks that teaching NOS throughout the year should benefit students in developing their NOS perception. She presents her ideas as follows:

> "My experiences were generally positive. It was mostly about getting the children accustomed to it. I only had a really hard time with my 6th graders. The 5th and 7th graders grasped it quite well, but with the 6th graders, most of my time was spent trying to convince them, as they were generally more problematic. I believe the children's individual characteristics also play a role in this. Overall, it was a good experience—more like an introduction. It feels like if the children were exposed to this for a whole year, then it would be truly sufficient. This was more of a warm-up. Even now, when I ask questions, they give answers that are close to being correct, but not entirely precise. They still need some time. But overall, I think it went really well." (Aylin, post-interview)

Teachers are also asked for their ideas on whether it is possible to teach RFN categories. According to her, NOS categories can be taught to some extent, but teaching the FRA Wheel directly can be challenging. Therefore, figuring out how to integrate these categories into science issues is very important. For example, she believes that teaching the Brandon Matrix to students can be difficult. She is also asked which NOS categories are the best and worst for learning and teaching NOS. She struggles the most with the scientific methods category of RFN. In the M workshop, providing different examples helped her differentiate various scientific methods, but she still finds it challenging to teach the Brandon Matrix to her students. The teacher is also asked how participating in this PD program affected her science and NOS teaching. She believes that her mind became more active, allowing her to see diverse aspects of scientific issues. She states her ideas as follows:

> "As I mentioned earlier, we, as teachers, often complain about the same things, but we rarely take action. However, trying something different in my own lessons has enriched me as well. My mind became more active, and I became quicker. While teaching, I found myself being more agile, quick question-and-answer exchanges, and suddenly, I realized that the students had already learned the topic. I saw that teaching a lesson isn't just about solving questions, explaining topics, and having students take notes. It's also about helping them see things from different perspectives, and I realized how valuable that is. So, in that sense, I can say I've grown professionally." (Aylin, post-interview)

Teacher Aylin shares her thoughts on how she views herself in teaching NOS. She believes that she still needs time to internalize RFN categories. She expresses her ideas as follows:

> "I know I still have a way to go. Ideas come to my mind, and I implement them well, but I can't yet sit down from scratch and say, 'Alright, let me write something about scientific practices.' As you can see, I still mix up concepts sometimes. That could also be due to mental fatigue because I'm simultaneously receiving training from various fields, and my mind sometimes feels overwhelmed. That's why, before each lesson, I need to go through everything in my head. So, I don't feel fully ready to say, 'I've got this down, I can even teach it to others.' But if I catch the right moment in my own lessons, I believe I can score a goal." (Aylin, post-interview)

Aylin's Observation Forms

Aylin's first teaching observation (implementation of the MIX1 lesson plan). Teacher Aylin's MIX1 lesson plan was observed by the researcher. The lesson plan was developed for a 5th-grade science subject titled "melting, freezing, and boiling points of pure substances and their graphs." The implementation lasted 80 minutes across two lessons. There were 19 motivated students in the classroom.

In the teaching part, the teacher began the lesson by reviewing the previous topic and engaged students with the question, "On the basis of which properties are matters classified?" Students answered that shape, color, taste, size, weight, and softness are the properties. The teacher then asked, "If two matters, water and ethyl alcohol, were shown to you, how would you distinguish them?" After considering students' answers, she connected this to NOS, asking, "How could scientists distinguish them?" She explained the boiling points of liquids and asked similar questions regarding solids and gases. Teacher Aylin used PowerPoint presentations and displayed images of the boiling points of water and ethyl alcohol. She tried to give each student a chance to speak and consistently encouraged them to think like scientists. She clearly demonstrated the difference in boiling points through her presentation. By the end of the discussion, students learned that the boiling point is constant for pure substances. Graphs were drawn for each matter, and students were asked NOS-based questions such as, "Do you think conducting this experiment once is enough to gather information about water boiling at 100 degrees and alcohol boiling at 80 degrees?" and "In what ways do scientists disseminate their research?" They responded with answers including books, journals, documentaries, newspapers, videos, conferences, etc. Teacher Aylin emphasized the reliability of scientific studies and the differences between scientific sources and others. Finally, she asked, "In which places do scientists conduct their studies?" The teacher successfully integrated NOS questions into the lesson.

In the second lesson, she continued to ask questions about NOS, such as "Why do scientists conduct these studies? How are these studies important for us?" Students answered, and the teacher gave daily life examples, such as "to prevent us from harmful materials, develop new products, and utilize that knowledge to generate further discoveries, etc." She continued to ask, "Why is it important to share these scientific studies with

society?" Her questions were beneficial for incorporating NOS into the science lesson. Then, she provided two example solids and emphasized the differences in their melting points. Moreover, she taught that for the same matter, the melting and freezing points are the same and that the duration for melting and freezing can change based on the amount of the matter. Additionally, based on the table, a graph for melting and freezing points was drawn, and students were informed about drawing graphs. In the evaluation part of the lesson, teacher Aylin wanted students to draw a graph based on the table on the smart board. The teacher moved around the classroom, reviewed students' graphs, and offered clarifications on any misconceptions. She also emphasized how scientists use common language through graphs, tables, etc. She evaluated NOS objectives through questions and answers.

It can be said that Teacher Aylin internalized the issues related to NOS and taught effectively in her lessons. She made strong connections to NOS, adhered to the lesson plan, and encouraged her students to actively participate in discussions and make inferences about tables and graphs. She managed time effectively. However, students could engage more actively through group activities, and NOS evaluations could also be conducted in writing. Thus, her teaching score is (34/36), which is very good.

Finally, she reflected on her experiences regarding what went well in the lesson, what she learned about planning and teaching, what the students learned, how she can assess this, and what she will do to improve the lesson and develop professionally. It seems that the teacher's awareness was high; she evaluated her lesson objectively and effectively observed her students. Her final score was calculated as 46 out of 48.

Aylin's second teaching observation (implementation of the MIX2 lesson plan). The second lesson (MIX2) observed by the researcher was taught to seventh-grade students. The science topic covered was pure substances, including elements and compounds. The implementation lasted 40 minutes within one lesson hour, and there were nine students in the classroom.

The teacher implemented the lesson plan with some changes. For example, the lesson plan lacks objectives for the SK category of NOS; however, as she began the lesson, she reminded students of the TLM plate through a PowerPoint presentation. To distinguish

between elements and compounds, she constructed a story in which scientists make comments about an exploration of some particles. Based on the text, teacher Aylin asks how scientific knowledge is disseminated. After taking the students' answers, she explained that it is disseminated through articles, seminars, theses, etc. The text then discusses whether the findings about particles represent elements or compounds. In the text, scientists make predictions and inferences. Again, the teacher connected this to models in science and the cumulative development of scientific knowledge. She encouraged her students to think like scientists and made a connection to theories, laws, and models, explaining their differences and how scientists use prior knowledge to develop new insights. Moreover, she posed the question of whether scientists conduct one or more experiments during the development of new knowledge and why. Students discussed this and concluded that multiple experiments enhance the reliability of scientific studies. The text continues with a discussion among scientists about the structures of elements and compounds using models. Teacher Aylin asked what benefits arise when scientists hold different, opposing viewpoints on an issue. The students answered that such discourse fosters questioning, leading to the discovery of various methods and theories. This process can spur new studies, providing diversity. The teacher reminded them of the TLM wall and emphasized how it facilitated scientific understanding. Finally, the text distinguishes the particle, and the teacher explained the differences between elements, compounds, and molecules by showcasing diverse models of each. The teacher also continued with textbook examples through a question-and-answer format. Students distinguished between the models of elements and compounds with reasoning. Lastly, she posed questions such as "What is being researched at CERN? Are there only scientists from one country at CERN?" She also inquired about the situation of Türkiye regarding CERN, asking, "Why should the support of multiple countries be required in a place where scientific research is conducted?" Students shared their thoughts on each question, and at the end, the teacher provided an explanation. She emphasized the role of funding in scientific studies, the commercialization of scientific knowledge, the functions of universities and nations, and the benefits of science with examples from technology.

In her second lesson implementation, teacher Aylin effectively taught science and NOS issues. She referred to all objectives in the lesson plan during her implementation. Although financial issues in science were not mentioned in the lesson plan, as it was stated as an objective, she still addressed it. She made connections through questions and answers.

She prepared a PowerPoint presentation for visuals and questions. She encouraged her students to actively participate in discussions. She managed the duration effectively. The second implementation was like the first one in that it did not include group activities but focused on intense question-and-answer sessions. Consequently, the score for the second teaching is (32/36), which is good.

Finally, she reflected on her experiences for the implementation of the second lesson plan. It seems that the teacher's awareness was high; she evaluated her lesson objectively and observed her students effectively. Her final score was calculated as 44 out of 48.

Aylin's Journals

Throughout the first five weeks, the teacher's reflections demonstrate that she adopted a structured and engaging approach to teaching various aspects of science. In Week 1, she focused on the aims and values of science. Students showcased their ability to articulate thoughts and defend perspectives using evidence. The lesson encouraged them to explore scientific reasoning beyond just factual knowledge, allowing them to experience one of the fundamental aspects of the nature of science—defending claims with justification. However, some students shared similar viewpoints, which limited the range of discussion. If repeated, diversifying perspectives through pre-assigned roles or case studies could enhance engagement. Students' enthusiasm and ability to provide accurate responses during the assessment phase indicated a strong grasp of the topic. Week 2, centered on scientific methods, revealed a challenge: students had difficulty due to limited prior knowledge. Despite this, their engagement remained high as they enjoyed answering questions. This struggle highlighted the necessity of reviewing foundational concepts before introducing new methodologies. Adjustments, such as incorporating a preliminary review session, could help ease students into complex ideas more effectively. By the end of the lesson, they understood changing variables and manipulation, though further reinforcement could enhance retention. Week 3, emphasizing scientific practices, was particularly successful. Students displayed high readiness and enthusiasm, which made discussions highly interactive. The strength of the lesson plan lay in its hands-on nature, allowing students to engage directly with scientific practices. The only area for improvement was time management, as activities could have been structured more efficiently. Nevertheless, students effectively articulated scientific processes and demonstrated confidence in

explaining their reasoning, suggesting that experiential learning reinforced their understanding. Week 4 focused on scientific knowledge, and students actively participated in discussions, offering diverse perspectives. As anticipated, some misconceptions surfaced, but these were effectively addressed through targeted discussions, leading to conceptual clarity. The ability of students to comment on different types of scientific knowledge indicated meaningful learning. A potential enhancement could be integrating interdisciplinary examples to broaden their understanding and application of scientific concepts across various domains. The teacher believes that students reached the learning goals because they could answer the questions. In Week 5, covering the social and institutional aspects of science, the lesson structure successfully engaged students, particularly through relatable examples such as CERN. The use of real-world applications increased their curiosity, and students expressed a desire to learn more. This highlights the importance of incorporating contemporary scientific institutions into science education. Given the enthusiasm, expanding the content with more real-life cases and historical examples of scientific collaboration could make the lesson even more impactful. The lesson effectively conveyed the collaborative and evolving nature of scientific knowledge, a crucial realization for students. She states her ideas for the 6th week as follows:

> "The students really enjoyed the question-and-answer sessions and brainstorming activities. Due to the inquisitive atmosphere in the classroom, they adapted to the topic very quickly. The only challenge was managing the class when one student wanted to answer more frequently than the others. Differing from the lesson plan, we could have requested experimental materials from the administration and conducted a real experiment. The students learned about the distinguishing properties of substances, including phase transition temperatures, and they commented on the importance of this knowledge in everyday life. Their responses to the questions were quite successful, which makes me believe they will apply what they learned in future lessons. As I asked questions from different perspectives, both the students and I became increasingly excited. They discovered many aspects of the nature of science, which changed their perspective on the subject. As a teacher, witnessing this was truly rewarding." (Aylin, teacher journal, week 6)

In the final two weeks, which integrated multiple aspects of the nature of science, students demonstrated deeper engagement and improved adaptability. These two lesson plans were observed by the researcher. According to the teacher, in week 6, students showed high participation in brainstorming and questioning activities. The lesson's inquiry-based approach enabled students to make meaningful connections, but managing class participation became a challenge as some students dominated discussions. Implementing structured turn-taking or small-group discussions could help balance participation. The lesson effectively connected aims and values, scientific practices, and social-institutional

aspects of science through real-life scenarios, strengthening students' ability to contextualize their learning. In Week 7, students successfully followed structured directives and provided insightful responses. They demonstrated an improved ability to analyze scientific practices and make connections between different concepts. Some students struggled with interdisciplinary connections, suggesting that more guided discussions or scaffolded questioning techniques could aid in linking topics. Extending the assessment period could also help consolidate their understanding. A key success was students referencing lesson examples in later discussions, indicating knowledge retention and conceptual understanding.

Considering all reflections, it is seen that the teacher implemented all lesson plans. She had only difficulty in implementing the lesson plan for the scientific methods category of RFN. Her students' motivation was generally good, and she did not encounter problems while implementing her lesson plans. She thought that her students reached learning goals and lessons were meaningful for them. Students became more familiar with NOS categories, and they started to refer to NOS issues in other lessons too. For the lesson plan referring to the scientific methods categories of RFN, the teacher had difficulty in reminding them of their previous knowledge about variables. It can be said that the teacher's teaching approach encouraged exploration, inquiry, and analytical thinking. The integration of real-world examples, hands-on activities, and structured questioning strategies enriched students' perception of science.

Aylin's Group Discussions

After implementing their lesson plans, teachers first shared their experiences in small groups before discussing them collectively in a whole group setting. Analysis of the reflection and discussion sessions from the workshops revealed that Teacher Aylin leveraged the advantages of her private school's good physical facilities and the strong prior knowledge of her students. For instance, to teach the SK category of the RFN, she showed a video explaining the differences between scientific theories and laws. Her students were highly engaged, asked insightful questions, and demonstrated a clear understanding of the concepts. Additionally, they effectively interpreted the TLM table, showcasing their ability to connect NOS concepts to scientific content.

Due to the small class size, Aylin managed discussions efficiently, ensuring every student had the opportunity to express their ideas, which fostered a collaborative learning environment. However, she faced some challenges. Aylin occasionally felt anxious about time management, striving to balance NOS objectives with core science content effectively. Additionally, in some classes, such as with her 6th graders, students struggled to interpret graphs, which hindered their ability to fully grasp certain NOS concepts. To address this, she recommended incorporating more examples, particularly for the M and SK categories, to enhance NOS comprehension. She suggested in a whole group discussion that there should be systematic teaching for permanent learning.

4.2.2.2. Case 2 – Beren's Teaching Practice. To examine how Teacher Beren applied her NOS understanding in her teaching, four data sources, which are individual interviews, teacher journals, observation forms, and group discussions during the workshops' reflection and discussion sessions, were independently analyzed.

Beren's Interviews

Teacher Beren is asked how she sees herself in terms of teaching NOS before the intervention. She thinks that she refers to NOS in many aspects, such as universality, development of scientific knowledge, and falsification of NOS. On the other hand, she does not prefer to mention hypothesis testing. She expresses her ideas as:

> "I believe that I have provided the foundation for teaching the nature of science. I explain to children that science is universal, that it develops under challenging conditions, and that every scientist progresses through a great deal of effort and many mistakes. However, beyond that, I do not provide very technical information. For example, I do not give instructions like 'this is how a hypothesis is formed' or 'this is the correct way to formulate a hypothesis.' But I believe that I provide them with a general education on the nature of science. Even though I do not go into great detail, I think I convey the overall idea." (Beren, pre-interview)

After the intervention, teacher Beren is asked about her experiences with teaching NOS. She thinks that she made efforts to integrate the NOS into classroom practices. In reflecting on her experience, she observed that students could sense when a different teaching approach was being used, even if they could not pinpoint exactly how. This change in approach seemed to engage students more, even in large or challenging classrooms. The teacher noted increased participation, with students actively discussing and debating scientific ideas, mirroring the thought processes of scientists. She recognized that while

students may not have fully grasped the diversity of the scientific method, they retained key concepts related to the aims and values, and social-institutional aspects of science. The teacher also identified opportunities for improvement, such as incorporating more discussions and emphasizing the historical development of scientific laws in future lessons. This reflection suggests a growing confidence in applying the NOS in teaching and a willingness to refine instructional strategies further. She conveys her ideas in the following way:

> "… Maybe it's because I start the lesson differently, or maybe my excitement or nervousness is different—I'm not sure. But the children already recognize that we are about to have a different kind of lesson while I implement the lesson plans, and I think they really enjoy it. Even in my most crowded class, even in the class I would call the most mischievous, I received very positive feedback when I applied these methods. The students participate more in the lesson. As I said, they really enjoy thinking like scientists. I also noticed that when one student shares a comment, another responds with something like, 'I agree with that, but it could also be this way,' creating a discussion environment while implementing the NOS activities in my lesson plans. I think I can further increase such small discussions in the future. Let's say we move on to a new topic. For example, what topic will I be teaching in the second semester? Light—maybe I can address this again in the context of how light propagates. There was a law related to this, Snell's Law, if I remember correctly. Maybe I can talk about this scientific knowledge and how it was discovered…" (Beren, post-interview)

The teacher is also asked whether teaching RFN categories is possible or not for teaching students, and which RFN categories are easy, and which are hard to teach. Based on her response, it is evident that she believes all RFN categories can be taught in science lessons, though some are more challenging than others. The teacher finds that teaching the AV of science, as well as SI aspects, is relatively easy, as these concepts can be reinforced throughout different units. Scientific practices are the easiest to implement because they naturally integrate into classroom activities such as making predictions, conducting observations, and engaging in discussions. However, the teacher encounters difficulties with scientific methods and methodological rules, as well as scientific knowledge. One of the main challenges is that these concepts require a higher cognitive level, which can be difficult for younger students, such as fifth graders. Additionally, integrating these categories into lesson topics is challenging unless the subject matter is particularly suited for it. The teacher notes that, in some cases, teaching the lesson content and explaining the NOS felt like handling two separate subjects rather than seamlessly integrating them. Time constraints also posed a challenge, limiting the depth of explanation and student engagement. She reflects on the importance of effective lesson planning and acknowledges that certain aspects, like providing concrete examples for scientific knowledge, could have been improved. Despite

these difficulties, she remains committed to refining the approach, considering ways to incorporate more structured discussions and better lesson designs to enhance students' understanding of the NOS. She presents her ideas as follows:

> "Of course. First of all, the AV of science can definitely be taught. SK may not be suitable for every topic or unit, but there are some excellent units where it fits well. For example, the structure of the atom, its history, the periodic table, or even a very basic version prepared for 5th graders could be appropriate. I also believe that M can definitely be applied. However, I found scientific methods particularly challenging. To explain variables in scientific methods, I gave several key points that students only remembered. I think their understanding was temporary—if I asked them about it in the next lesson, they probably wouldn't remember because we didn't provide enough examples or clearly explain the differences. We already see scientific practices in nearly every unit, so they can be easily incorporated into their respective units. However, I had no trouble teaching the AV of science, as well as SI aspects of science. While comparing the categories, M was very difficult to teach. I also struggled with SK. The main reason for this was that I was only working with 5th graders. If I had been working with higher levels, it might have been easier to convey. Additionally, I found it difficult to integrate these categories into the topics because, for effective integration, the subject matter needs to be very suitable. I ended up teaching both the topic and the NOS at the same time, which made it feel like I was teaching two separate lessons…. There was also the issue of time management, as I couldn't spend too much time on planning and explanations." (Beren, post-interview)

Teacher Beren is also asked how she sees herself teaching NOS after participating in the PD program and implementing her lesson plans. She believes that she felt adequate in each category. The teacher feels responsible for addressing these misunderstandings, particularly the notion that scientific knowledge can only be generated through experiments and experimental results. To counteract these misconceptions, the teacher emphasized the importance of repeated reinforcement and clear explanations in lessons. When asked if there were any categories of the NOS that she felt inadequate in teaching, the teacher admitted struggling with explaining scientific knowledge at a level that middle school students could understand. They felt that they were unable to effectively simplify complex concepts to match students' cognitive levels. Additionally, she found it particularly challenging to explain variables in scientific methods, recalling that even while preparing and delivering lesson plans, they struggled with these topics. Although her difficulty was not due to a lack of knowledge, she felt inadequate in communicating the content in an accessible way for students. The teacher acknowledged the need for personal improvement in these areas and considered engaging in additional self-study to enhance their teaching approach. She states her ideas as follows:

> "I actually feel somewhat responsible. Students have a lot of ideas; they think science is done in a completely different world. They are not aware that scientists are people just like us, living lives similar to ours, and that they are curious and inquisitive individuals. I honestly feel responsible for correcting this fundamental misunderstanding. There are such misconceptions that children believe. For example, they think that scientific knowledge can only be created through experiments and experimental results. … To change these misconceptions, I believe repeated emphasis and clear explanations should be provided. When explaining scientific knowledge, I feel that I am unable to adjust to the students' level of understanding… I also feel very inadequate when explaining the variable aspect of scientific methods…. Maybe I can work on this myself. These were already the categories I struggled with both during preparation and implementation. I feel inadequate not in terms of knowledge itself, but in terms of conveying it effectively and presenting it in a way that matches the students' level of understanding." (Beren, post-interview)

Beren's Observation Forms

Beren's first teaching observation (implementation of the MIX1 lesson plan). Beren's first lesson plan (MIX1), observed by the researcher, was implemented for 5th-grade students on the topic of melting, freezing, and boiling points of pure substances. The lesson plan was developed with teacher Aylin. Teacher Beren's implementation lasted 80 minutes, two lesson hours. There were 26 students in the classroom.

In the teaching part, the teacher started her lesson by asking, "How can we classify substances?" (solid, liquid, gas). "So, how do scientists distinguish matters while classifying them? Could we touch, smell, and taste each matter? Which properties of matter do they pay attention to while classifying them? The teacher opened a PowerPoint presentation and showed a picture of two glasses with water and ethyl alcohol. She asked students the question, "Without tasting and smelling, how do you distinguish them?" (freezing, melting). "What are your predictions?" She encouraged her students to answer. The teacher showed the temperature-time table of two liquids and asked why the temperature remains stable for some time intervals (phase change). Students observed that water boils at 100°C, while ethyl alcohol boils at 80°C. Here, the teacher taught how to draw a phase change graph based on the temperature-time table. She emphasized that in the graph, the temperature remaining constant indicates a phase change. The teacher made a NOS connection by asking, "You know scientists draw these graphs. Do you think it is enough for scientists to do this only once? Why?" (The liquids may not be pure, the environment can affect the results, they can reach different findings, they can use diverse materials.) "Where scientists conduct their studies?" (laboratories, NASA, Turkish Space Agency, TÜBİTAK, universities, etc.). She continued to ask, "For 2 solids, how do you distinguish between aluminum and magnesium?"

(Looking at hardness, softness, melting point, and the visual appearance.). In the diagram, she showed the melting points of two solids. Students reached the conclusion that pure solids have a specific melting point. Students examined the melting graphs of two solids and reached the conclusion that during phase change, the temperature remains stable for solids, too. Also, students are asked to notice that the melting and freezing points are the same for a pure solid, which is a distinguishing characteristic of these substances.

In the second lesson, she summarized the previous lesson and mentioned boiling points for pure substances. She continued to emphasize that the boiling point is not dependent on the mass of the substances; mass only affects the duration of boiling. The teacher wanted students to draw graphs for the given phase change graphs. She drew the first one on the board and wanted students to draw the second one in their notebooks. She visited all the students and checked their graphs. Finally, she drew the graph on the board. Then, the teacher made a NOS connection by asking, "How do scientists share their findings with other people? (by articles, meetings, journals, mass media, conferences, online meetings, etc.)

She encouraged her students to actively participate in questions and answers and make inferences about tables and graphs from simulations. From the beginning to the last part of the lesson, she did not refer to any NOS issues. She asked NOS-based questions at the end of the lesson. If there had been more time, the students could have thought more about NOS questions; NOS evaluation could have been done in a written way, too. On the other hand, she referred to all the objectives stated in the lesson plan. It can be said that Teacher Beren was proficient in the lesson content and the NOS emphasis. Thus, her teaching score is (32/36), which is very good.

As a result, teacher Beren reflected on her experiences about what went well and what went wrong in the lesson, and what she will do to improve this lesson and develop professionally. She was confident after the implementation. Her final score was calculated as 44 out of 48.

Beren's second teaching observation (implementation of the MIX2 lesson plan). Beren's second teaching observation was done by the researcher for the 5th-grade students

on the topic of expansion and contraction. The teacher started the lesson by showing a closed jar and asked, “How can I open this closed jar?” (using a spoon, knife, cloth, or hot water). The teacher showed a video in which a crushed ping pong ball returns to its original shape in hot water. She asked, “How did the ping pong ball return to its original shape? Despite no air being added from the outside, how did the ball return to its original shape?” “How to enlarge a ring that is stuck on a finger?” (applying force, melting and freezing, or placing it in hot water). Before showing the video from the EBA, the teacher described Brandon’s matrix. She drew two plants on the board, one receiving sunlight and the other not, and asked what the aim of this experiment was. She explained the variables and hypothesis testing. By drawing a 4x4 table on the board, they indicated that in some studies, controlled experiments are conducted based on hypotheses, but in some not. She opened a simulation from the EBA and asked students for their predictions for the change in size of the material. For the second step, students were asked to determine methods that prevent the ball from passing through the rings (such as heating the ball or cooling the ring). The teacher also wanted students to construct their hypotheses and test their hypotheses. The teacher continued with another video from the EBA about the expansion of liquids. In the video, the liquid alcohol is heated on a stove, and the volume of the liquid increases. She asked similar questions for the expansion of liquids. She explained the expansion and provided examples for the extraction of liquids. She summarized all the examples about the expansion and contraction that they talked about during the lesson.

In the second lesson, the teacher started the lesson with examples of extraction and contraction. She asked, "How do you think it was first discovered that materials expand and contract?" (by accident, by chance, experiences) “Could a single trial be sufficient while conducting this experiment?” (We need to be sure that the knowledge is correct before disseminating a result) “What do you think learning that heated materials expand can provide us? What purpose might this information have been questioned for?” (It helps us understand many topics we observe in daily life; scientists conduct research and publish their findings to benefit society as a whole). After asking NOS based questions, the teacher deepens the topic by providing examples of expansion and contraction from daily life and asked students to classify them such as the expansion of train tracks and power lines in summer, the balloon bursting due to over-expansion in hot weather, the rise of liquid in a thermometer, the deflation of a ball in cold weather, the contraction of power lines in winter, the flight of hot

air balloons, the deflation of bicycle tires in cold weather, the cracking of a glass filled with tea, the fitting of lenses into eyeglass frames. The teacher opened three videos about the expansion of solids, liquids, and gases. She summarized the topic. In the evaluation part of the lesson, a chart table including scientific practices and activities done during the lesson was shown, and students were asked which scientific practices they experienced during the lesson. Students also answered science-based questions through fill-in-the-blank questions. Finally, the teacher asked, “Do scientists receive financial support?” This question was not in the lesson plan.

The teacher was in control of the lesson. By making small adjustments to the plan, they applied all parts during the class. The NOS (Nature of Science) emphasis was appropriate. The teacher tried to engage the students actively with question-and-answer sessions. They used the smartboard to show videos and simulations, and used different materials. The score they received for the teaching section is 34/36.

In the reflection section, the teacher reflected on her experiences with the implementation. According to her, students comprehended the science topic of expansion and contraction through simulations, videos, explanations, and daily life examples. She thought that the Brandon matrix was not totally grasped by the students because each type of scientific method was not taught to the students. It was not the aim of this lesson. However, students’ awareness of the existence of the scientific method increased. Her total score was calculated as 46/48.

Beren’s Journals

Throughout the first five weeks of implementing the lesson plans, the teacher faced various challenges but also observed notable improvements in student engagement and understanding. In Week 1, due to personal health issues, the lesson did not unfold as planned, with the teacher skipping parts of the lesson and struggling to maintain classroom control. This resulted in an incomplete explanation of the friction force and the inability to assess students' understanding through planned evaluation methods. However, the teacher did attempt to introduce the NOS by assigning students the role of scientists. One of the photos she shared from her first implementation is shown below in Figure 4.31.



Figure 4.31. Beren's photo from the implementation of the first lesson plan.

In Week 2, the lesson plan was better executed, with the teacher emphasizing the NOS beyond the standard curriculum. Despite students struggling with the explanation, they showed an understanding of friction forces through observation and guided questioning. However, technical difficulties, such as a lack of photocopies, hindered the planned evaluation. The teacher noted that allocating more time for assessment would improve future lessons. Week 3 highlighted an increase in student participation and curiosity. Students responded well to the water cycle model and engaged in discussions about scientific practices. The teacher observed that students could intuitively sequence scientific practices but required further clarification on the non-linear nature of these practices. The lesson extended beyond the allocated time, and the planned assessment could not be conducted, leaving the teacher uncertain about the students' overall comprehension. Week 4 focused on scientific knowledge, where students displayed some misconceptions about theories, laws, and models. The inclusion of an English animation video did not aid comprehension, leading to an impromptu teacher-led explanation. Despite repeated clarification, some students still struggled to differentiate between theories and laws, prompting the teacher to reconsider the instructional approach. The teacher realized that generating curiosity through thought-provoking questions could have made the lesson more meaningful. Week 5 introduced the social and institutional aspects of science. The teacher observed high student engagement, particularly in discussions about scientific collaboration and institutional support for research. However, unexpected content in an interactive video caused some confusion.

Despite a reduced lesson duration, students demonstrated a good understanding of how scientific knowledge is shared and validated. The teacher concluded that this aspect of science was easier for students to grasp compared to more abstract concepts like scientific knowledge classification. She expresses her thoughts for the 5th week in this way:

> "While implementing the lesson plan, student participation was very good. Although their prior knowledge (state changes of matter, the difference between evaporation and boiling) was not fully established, I believe their predictions were very accurate… The interactive videos contained more information than the part I was going to explain. Because of this, I struggled to explain the topic to the students. … Instead, I would have found an interactive video or simulation from a different source or drawn the experimental setup on the board and asked the students to interpret it. I couldn't assess the students in terms of the MEB learning outcome, but considering their answers to the questions throughout the process, I think they understood the part I explained… The students realized that scientists do not directly accept conclusions but consult their colleagues, and that scientific knowledge must be validated collectively. They also learned that this knowledge is shared through articles and journals by institutions such as TÜBİTAK, universities, and research institutes that financially support scientific research. Students grasp the SI dimension of science better than other aspects. Considering their cognitive development level, I think I could teach this dimension more effectively to 5th graders." (Beren, teacher journal, week 5)

In Weeks 6 and 7, the teacher implemented lesson plans incorporating at least two NOS categories. Also, these lesson plans were observed by the researcher. In Week 6, students remained engaged throughout the lesson, responding well to the initial questioning. However, they struggled with interpreting phase change graphs, which the teacher had initially underestimated. Adjusting the lesson plan by dedicating more time to this concept would have improved understanding. Despite this, students successfully engaged in scientific practices such as observation, measurement, and graphical representation, making the lesson meaningful. Week 7 continued this approach, using real-life problems to spark student interest, which increased participation. However, difficulties arose in explaining expansion and contraction, requiring extended discussion time. Additionally, the complexity of Brandon's Matrix led to confusion about hypotheses and variables, suggesting that a simplified version would have been more effective. Overall, the teacher noted that integrating multiple NOS concepts into a lesson enriched students' scientific perspective, making the learning process more holistic and impactful. She reported her general ideas for teaching NOS at the end of the seventh week as:

> "Teaching the NOS achievements does not happen all at once. The process takes some time. It is necessary to include the categories of the NOS in every lesson, even if only a little. In this lesson plan, I will also mention what I have noticed in other plans; students enjoy learning the NOS achievements. They participate more actively in the lesson and knowing that scientists also engage in the activities they do in class and learning scientific process skills truly makes them happy and motivated." (Beren, teacher journal, week 7)

Considering all reflections, teacher Beren had generally difficulty in teaching the scientific methods and scientific knowledge categories of RFN. Her all students were 5th grade, and the size of her classroom is high. Thus, she thought that maybe because of students' cognitive levels and classroom size, it became hard for her to teach these categories. She sometimes struggled to manage time. Thus, she could not be sure whether her students reach the learning goals or not. She believes that some NOS visuals can be simplified considering students' level such as Brandon Matrix and Benzene Ring Heuristic.

Beren's Group Discussions

Teacher Beren works in a public school located in an underdeveloped region of Istanbul, where her classes typically consist of 37–40 students. During reflection and discussion sessions in the PD workshops, she shared that the large class size made it challenging to conduct group activities, manage time, and facilitate discussions effectively. Her initial experiences implementing lesson plans were discouraging, as she struggled to fully execute the plans, manage time constraints, deliver science content, and establish meaningful connections to NOS concepts. For instance, when addressing the M category of NOS, she could only focus on constructing variables, leaving other aspects unexplored. Similarly, for the SK category, her students struggled to understand distinctions within scientific knowledge, and Beren found it difficult to link these NOS concepts to the science content, limiting the depth of instruction.

Over the weeks, however, Beren became more confident and relaxed, making deliberate efforts to integrate NOS connections into every part of her lesson plans. She adapted her approach by prioritizing simpler activities and clearer explanations to accommodate her classroom's constraints. When comparing her experiences with her group members, Beren generally faced greater difficulties in integrating NOS due to her large class size and limited resources. However, for certain categories, such as SI and MIX lesson plans, her experiences aligned more closely with those of her peers, as these lessons allowed for more flexible implementation. To improve NOS instruction, Beren suggested simplifying lesson plans, incorporating more NOS focused examples, and avoiding group work due to the school's limited physical facilities.

4.2.2.3. Case 3 – Deniz's Teaching Practice. In order to investigate how teacher Deniz translated her NOS understanding into teaching practice, four data sources, which are individual interviews, teacher journals, observation forms, and group discussion from the reflection and discussion sessions of workshops, were analyzed separately.

Deniz's Interviews

Teacher Deniz is asked how she felts herself for teaching NOS before participating PD program. She feels herself inadequate because she does not know what the meaning of NOS. She took a course about NOS during the university years, but this course did not include practicing. She shares her thoughts in the following way:

> "I feel myself inadequate because I don't fully understand the nature of science. I remember taking a course on the NOS, but I only remember it very superficially. Even at university, it was emphasized a bit more only in science-based courses. There, I probably didn't focus on it much either, as I strategically leaned towards other areas to get higher grades. So, I can say that I don't have extensive knowledge about the NOS." (Deniz, post-interview)

After the intervention, teacher Deniz is asked her experiences for implementing her lesson plans. She thinks that she has some struggles and feels still inadequate for teaching NOS. According to her, teaching NOS needs more knowledge about science and instructional practices. She thinks that before implementing lesson plans as a teacher she could consider potential problems and took some precautions considering her students' profile. Thus, she feels to develop herself more. She expresses her ideas as:

> "So, of course, there were some shortcomings. I also realized that there were deficiencies on my part. I noticed that because I didn't fully understand some things myself, there were points where I couldn't convey them properly to the children. But I believe that this can be overcome through continuous practice and integration. Mistakes could naturally be made at the beginning, and I think I made those mistakes. However, in my future professional life, I plan to apply this in a more structured and informed way. Now, I know my class well, and since I understand how to progress according to my students, I intend to use it again accordingly. So, for me, the NOS is an area where shortcomings do exist, but I have seen that in the next stages, these issues can be addressed with more attention." (Deniz, post-interview)

Teacher Deniz is also asked her ideas about whether teaching RFN categories is possible and which categories are easy and hard for teaching. She believes that integrating RFN categories of the into lesson plans is possible, though incorporating all five categories at once is challenging. She explains that at least three categories can be included in a lesson,

utilizing various resources such as articles and experiments to address aspects like scientific practices and social acceptance. She emphasizes the importance of starting NOS instruction as early as the 5th grade to build familiarity over time, making it easier for students to grasp complex concepts later. Regarding the difficulty of teaching different NOS categories, she found science knowledge category is most challenging. Teaching and integrating laws, theories, and models is difficult due to a lack of concrete examples. On the other hand, she found scientific practices the easiest to teach, followed by social and institutional aspects of science, as these were more comprehensible to students. Ultimately, she advocates for incorporating NOS into lesson plans, even if it is not explicitly required by the curriculum, to ensure long-term understanding among students. She presents her ideas as follows:

> "While integrating our lesson plan, we realized that incorporating all five categories at once is quite difficult, but we found that we could include at least three categories of the NOS in a way that aligns with our learning objectives. Therefore, we are able to integrate them. By utilizing various external sources, we can, for instance, publish an article and use it to discuss the social acceptance of science, its aims, and values. So, I believe it can be integrated. Of course, every school has a different student profile. However, I believe that if we start teaching these concepts in 5th grade and build the foundation early, students will recognize them by the second or third time they encounter them... I believe we, as teachers, should instill these concepts in our students and include them in our lesson plans, even if they are not explicitly required by the national curriculum. I struggled a lot with teaching laws, theories, and models. We had very few examples to illustrate these concepts to students. I feel like I couldn't provide enough examples. On the other hand, the easiest category to teach was scientific practices. I noticed that it was understood quite easily. Additionally, the social and institutional aspects of science were somewhat easier for students to understand. I think I can teach those more easily." (Deniz, post-interview)

Finally, teacher Deniz is asked how she feels herself while teaching NOS. The interview reveals the teacher's reflective approach to PD and her commitment to improving her instruction of the NOS. She acknowledges her past mistakes and gaps in knowledge, emphasizing the need for careful planning and more detailed explanations in future lessons. She believes that continuous practice will enhance her ability to teach NOS effectively and intends to integrate it more systematically into her lesson plans. Additionally, she identifies challenges in teaching scientific knowledge, theories, and laws, recognizing the need for further development in these areas. She also mentions difficulties in conveying the aims and values of science and notes that students struggle with Brown's Matrix due to a lack of familiarity. However, she remains optimistic, believing that with richer examples, these concepts can be better understood. Her responses demonstrate a proactive attitude toward self-improvement and a strong dedication to refining her teaching strategies. She shares her thoughts in the following way:

> "… I realized that I had shortcomings. What do I mean? Moving forward, I need to prepare a more careful plan, one that includes more explanations and specifies at which points I should address certain topics for students and how I should adapt my teaching. I believe that if I continue this process, I will gradually master it. I will proceed with more foresight, and my plans will be more structured, well-developed, and refined. Therefore, I am fully aware that I must include this in my lesson plans. As I mentioned earlier, I find it very difficult to teach SK, theories, and laws. I believe I need to improve myself in these areas. Additionally, I need to touch more on the AV of science. Regarding other aspects, students struggle to fully understand Brown's Matrix because they are not familiar with it. That one is slightly better compared to the others, but I believe it can be more effectively taught if I provide richer examples." (Deniz, post-interview)

Deniz's Observation Forms

Deniz's first teaching observation (implementation of the MIX1 lesson plan). Deniz's first lesson plan (MIX1), observed by the researcher, was implemented for 7th grade students. The topic was molecules. There were 10 students in the classroom.

In teaching, Teacher Deniz started to lesson by reminding the previous lesson. Without explaining the aims of the lesson, she directly asked "Do substances consist of only one type of atom, or are they formed by the combination of different atoms?" She opened the lesson plan on the smart board and showed the pictures of Lego pieces on it. She asked, "What do different Lego pieces resemble?" Here, the teacher was anxious about not having enough time and hurried, unable to provide clear instructions. Before the activity, the teacher did not establish a clear analogy between atoms and Lego pieces as the lesson plan was. The teacher did not explain to the students that Lego pieces, like atoms, combine to form a substance, and that pieces of the same colors could represent the same atom, while pieces of different colors could represent different atoms. The teacher directly moved on to the activity. This situation caused a contextual disconnection during the lesson. The teacher skipped that part of the lesson plan and moved directly to the activity section. She continued to ask, "Imagine that a scientific community has asked you this question, and you need to classify these molecule models." Students classified Lego pieces based on their colors. For example, atoms include orange and blue, which are in the same category, and the others are in different categories. The teacher explained the definition of elements and compounds as "molecules composed of a single type of atom are known as elements, whereas those consisting of different types of atoms are termed compounds." Then she classified 12 molecules with students as elements and compounds. In the final part of the lesson plan, teacher asked NOS based questions as "Why were models used in molecules? (She did not

answer) Why is classification being done? When the scientific committee evaluates your classification and explanations, which criteria do you think they will pay attention to?" (size, colors etc.). In this part, teacher Deniz could not explain the answers appropriately. Finally, she showed Brandon matrix table and explain this table shorty without giving examples and asked, "which scientific methods did we learn today?" (prediction (?), non-manipulation). In the evaluation part, teacher showed some molecule models to students and wanted them to determine whether they are element, compounds, and number of types of atoms. They filled the blanks in the table together. The teacher finished the lesson 10 minutes early and had students write related notes in their notebooks.

The teacher had difficulty implementing the lesson plan as it was. She probably did not internalize scientific method category of RFN and thus had the belief that Brandon matrix is not taught the students. She also felt anxious about time management, so she skipped some parts of the lesson plan, did not explain the questions clearly, and did not engage students to share their ideas. Her teaching score is determined as 24/36.

After the implementation, she shared her experiences about the implementation. The teacher had a positive opinion about the implementation of the lesson plan because she finished the lesson before the scheduled time, asked all questions related to NOS following the sequence in the lesson plan, and did not experience any problems in classroom management. The researcher shared her observation notes with her, and they discussed each part of the lesson plan. She asked questions about what she could take care of for integrating NOS issues. After the discussion, her awareness of the deficiencies in her implementation increased. She took notes for the other implementation. Her total score was calculated as 36/48.

Deniz's second teaching observation (implementation of the MIX2 lesson plan). Deniz's second observation was done for the 7th grade on the topic of molecules. The lesson lasted 40 minutes, one lesson hour. There were 6 students in the classroom.

In teaching, teacher Deniz started the lesson by showing the picture of succulent and asked, "What do you see on the board? Are these logos the same or different? What can these particles be?" (elements, compounds). She explained her analogy that, as a succulent

consists of different logo particles, substances consist of molecules. Then, she grouped students and explained the purpose of the activity. She distributed colorful atom model beads and wanted them to develop their models, considering the smallest particles of the succulent. She visited each group and answered tehri questions. Then, she wanted her students to present and explain their models. After group presentations, she asked, “You did different models for each other. If we want to develop a common model, what criteria should we have?” She explained that scientists need to reach a consensus. Here, the discussion was so limited. The teacher opened a video about elements, compounds and compounds from the EBA. She made explanation that elements consist of only one kinds of atoms, but compounds consist of at least two kinds of atoms, both can be form of molecule. Teacher opened a table including 5 kinds of molecular formula and asked the questions of “what the number of atoms, number of the types of atoms, and types of molecules for each molecular formula are. In the lesson plan, students were expected to model all these molecules. However, teacher Deniz did not follow the lesson plan as it was. After answering questions, she asked her students, “Why was classification done? What is the benefit of classification in science? (to distinguish differences among molecules). Teacher Deniz showed the visual of Benzene Ring Heuristics (BRH) and asked, “Which scientific practices do you think we used in BRH?" (classification, explanation, prediction, modelling). She also explained other scientific practices in BRH.

Teacher Deniz, in her teaching, was good considering time management, and evaluation parts. She used different teaching materials, such as visuals, videos, molecule models, etc. She directed many of the questions stated in the lesson plan, but she skipped some of the questions in the introduction parts and did not ask more questions to engage students to share their ideas or think more about the related questions. Also, her answers were limited. For example, she explained the role of classification as only distinguishing materials. She could mention other functions such as making comparisons, identifying patterns, making predictions, facilitating scientific communication, and making research more systematic. She could provide more examples from the history of science or other science topics that they classified in the past. Her teaching score was calculated as 30/36.

After the implementation, she reflected on her experiences that she wanted to develop herself compared to the previous lesson plan. Thus, she tried to focus more and ask all the

questions stated in the lesson plan. She provided enough time for the group activity and made all NOS connections. However, she reflected that she needed to improve herself by reading more about NOS. Her total score was 36/48.

Deniz's Journals

Throughout the first five weeks of implementing the lesson plans in the classroom, various aspects of science were introduced to students. Each week, a different dimension of science was explored, aiming to enhance students' understanding and engagement. During the first week, which focused on the aims and values of science, student participation was notably high. Their curiosity increased, which helped in maintaining the flow of the lesson. Adjustments, such as allowing students to take notes for better time management, were identified as potential improvements. Although students were engaged, assessment results indicated that some concepts were not fully grasped. Encouraging students to approach topics as scientists rather than passive learners proved beneficial in fostering deeper comprehension. In the second week, which covered scientific methods, time management was well-executed, and student involvement was strong. Despite a technical issue with a Flash application at the beginning, the session proceeded smoothly. The lesson effectively introduced students to the variability of scientific inquiry, highlighting that not all knowledge is acquired through the same methods. The students demonstrated a solid understanding during the evaluation phase, with only a few struggling to engage. The third week emphasized scientific practices, incorporating hands-on activities such as modelling a parachute and predicting the outcome of dropping an egg. Students participated eagerly and showed preparedness, making the lesson flow efficiently. However, a Friday prayer session disrupted the schedule in one class, leading to a 20-minute loss. Some students struggled to grasp the Benzene Ring Analogy, which could be addressed by allotting more time for clarification in future sessions. Overall, students demonstrated comprehension through active participation and accurate responses during assessments. The fourth week focused on scientific knowledge, and while the lesson followed the planned structure, an unexpected issue arose when students did not take a video presentation seriously. If the lesson were to be repeated, replacing the video with one featuring Turkish narration would be a better alternative. While the official curriculum objectives were met, some abstract concepts, such as laws, theories, and models, remained unclear for students. More examples and simplified

explanations would enhance understanding. Unfortunately, the lesson plan for the fifth week, which aimed to explore the social and institutional aspects of science, was not implemented due to unforeseen circumstances. Therefore, no reflection could be made for this week.

> "I was able to manage the time effectively. It went as planned. I applied it to three classes. My students came prepared and were eager to participate, which made the process easier…. However, students had difficulty understanding the Benzene Ring Analogy, so I had to explain it to them. I could add 10 more minutes for this explanation. I believe they did. Participation was high, and they were engaged and curious throughout the process. During the assessment phase, I generally received good responses. They started to view events around them from a different perspective. This increased their curiosity about the lesson. I think it broadened their horizon. We created a model by making a parachute, made predictions about whether the egg would break or not and why, flew the parachute, conducted an activity, collected data, explained why some eggs did not break and why others did, and connected this to real-world examples from daily life. These elements were incorporated into our lesson plan, making it more meaningful." (Deniz, teacher journal, third week)

During the last two weeks, the lesson plans focused on integrating at least two categories of the NOS into the curriculum. The researcher observed these teaching implementations. In the sixth week, the session was well-timed, and student participation was commendable. Students provided insightful responses during discussions. However, reflecting on the lesson, there was a realization that more time should have been dedicated to explaining concepts more clearly and providing constructive feedback. Although students achieved the curriculum objectives, there was room for improvement in reinforcing the NOS aspects. In the seventh and final week, the lesson plan effectively met its objectives. Students were actively engaged, and time was managed efficiently. However, some students were distracted by playing with molecular model beads, which slightly disrupted the lesson. The only modification needed in future applications would be refining certain question formats for clarity. Students' participation and responses indicated their understanding of the topic. Additionally, their exposure to different dimensions of scientific knowledge helped them comprehend the aims and values of science more deeply, addressing any previous uncertainties. By the end of the implementation, it was evident that students had developed a solid grasp of scientific practices and the social and institutional nature of science through engaging activities and discussions.

Considering all of Deniz's reflections, she implemented all her lesson plans except for the one in the 5th week, which was about the SI category of RFN. It can be said that the teacher successfully implemented her lesson plans, focusing on a different aspect of science each week based on her reflections. Student participation and interest were high, and the

lessons were made meaningful and engaging, especially through activities and interactive approaches. However, there were small challenges related to time management and materials in some weeks, and the 5th week (focusing on the SI aspects of science) was not implemented. According to her, more clarity and examples could have been given in some topics to make her lessons even more effective. On the other hand, it is observed that the teacher's reflections were not objective in some respects. For example, in the 6th week of implementation, the researcher noticed that the teacher had difficulty teaching the science of molecules and the scientific method. She also struggled to engage students in active participation through follow-up questions, could not provide enough time for the activity, and was unable to evaluate according to the lesson objectives. However, her reflections were quite positive. It may be because she was not aware of the quality of her teaching practice, or she avoided confrontation, that she needs more practice and internalize some RFN categories specifically for AV, M, and SK categories of RFN.

Deniz's Group Discussions

Teacher Deniz shares experiences similar to Teacher Beren. She is working in a gender-segregated public school in Istanbul where she teaches only male students in approximately 35–40 classrooms. Due to the large class size, she avoided group work, finding it difficult to manage effectively in her crowded classroom. Deniz strongly believes that students should take notes on science content as directed by the teacher to better comprehend scientific topics. However, since her lesson plans did not incorporate structured notetaking, she felt anxious about whether her students were grasping the science content and meeting the science objectives. The discussions indicated that Deniz tended to view NOS concepts as separate from the science content, which made it challenging to integrate them seamlessly into her lessons.

During whole-group discussions in the PD workshops, Deniz explained that her implementation of NOS-focused lesson plans was less effective due to her students' limited prior knowledge and skills. For example, many students struggled to interpret graphs, were unfamiliar with the concept of a hypothesis, lacked experience with group work, and, in the case of foreign students, faced language barriers that hindered their participation. Specifically, her 7th-grade students found it difficult to understand different types of

scientific knowledge, and the visual representation of the TLM table felt too abstract for them, further complicating their grasp of NOS concepts. Despite these challenges, Deniz reflected positively on some outcomes, noting that the NOS activities engaged her students, sparked enjoyment, and motivated them to think critically about diverse aspects of NOS, such as the role of evidence in scientific inquiry. To improve, she suggested incorporating more concrete examples and scaffolding to make NOS concepts more accessible, particularly for students with limited foundational knowledge.

4.2.2.4. Case 4 – Leyla's Teaching Practice. To explore how Teacher Leyla integrated her NOS understanding into her teaching practices, four data sources, which are individual interviews, teacher journals, observation forms, and group discussions held during the workshops' reflection sessions, were examined as follows.

Leyla's Interviews

Before the intervention, teacher Leyla is asked how she sees herself teaching NOS in her lessons. Her response highlights time constraints as a key challenge in integrating the NOS into lessons. She acknowledges NOS is important but admits she doesn't devote enough time to it. Instead, she incorporates it when relevant but does not systematically emphasize it as a separate concept. She also recognizes that without intentional planning, NOS tends to be overlooked in spontaneous classroom discussions. However, when she has the opportunity to carefully design a lesson, she ensures that NOS is included. She gives an example of discussing the Apollo 11 mission, where she deliberately considers aspects such as the teams involved, the support they received, and the societal impact of the event. She finds it difficult to implement NOS effectively due to a dense curriculum and limited lesson time. Her response suggests that while she values NOS instruction, structural constraints hinder its consistent and impactful integration into her teaching.

> "I mention it when relevant, but I never have students take notes under a separate heading or explicitly state, "These are the characteristics of science, this is what we did here." I address it when it comes up naturally. So, I wouldn't say I feel inadequate in this area, but maybe it could be done better. However, due to time constraints, I can't be effective. But when I take the time to sit down and carefully plan a lesson, deciding what I want students to do and what questions I will ask, I make sure to incorporate the NOS. E.g., in the lesson where I talked about the Moon, I used the Apollo 11 mission as an example: Who was involved before the spacecraft was sent? How many people were in the team? It requires prior preparation. But as you know, the curriculum is packed, and our lesson hours are very limited." (Leyla, post-interview)

After the intervention, teacher Leyla is asked about her experiences with teaching NOS. She highlights the positive impact of the PD program on classroom practices. She emphasizes that the lessons took on a new format, incorporating different types of questions and new discussion topics, which made the learning experience more engaging for students. This shift allowed students to encounter and explore concepts in a unique way compared to traditional methods. Additionally, she mentioned that students, who often compare their lessons with those of other classes, found this approach distinct and memorable. Since it was not a commonly used method, it increased retention and even led students to reference it in later discussions. Overall, the teacher sees the experience as beneficial, as it introduced a novel instructional strategy that enhanced student engagement and comprehension. She puts forward her ideas in this manner:

> "Well, it was nice; our lessons took on a different format in the end. We had content that we examined, then we paused, took a break. We asked different questions, brought up different topics. They heard and saw different things. It was an unusual practice. And you know, children interact with other classes as well. They observe how other classes approach the topics, what methods they follow, or when they look at other reference books, they couldn't find anything like what we were doing. This made it a unique experience for them. So, I think it was a good thing, and since it was a different lesson plan, it became more memorable because it was a rarely applied method. That's why sometimes they even refer to it." (Leyla, post-interview)

Based on her experiences of teaching RFN categories, teacher Leyla is also asked whether teaching all categories of RFN is possible and which categories she finds easy or hard. She acknowledges that integrating the NOS into science lessons is possible but emphasizes that it can be challenging to cover all aspects comprehensively. She emphasizes the importance of incorporating NOS elements progressively across different grade levels to ensure continuity. She provides good suggestions for teaching each category of RFN. She presents her ideas as follows:

> "I think it is definitely possible. Of course, it can be difficult to address every aspect of the NOS in every topic. It can be covered, but I believe there may be some disconnections. Therefore, if we consider the curriculum as a process for each year and each level, I can say that there are certainly categories that can be integrated into the NOS. For example, by analyzing a scientific study, one can evaluate the AV. Questions such as how objective the presented work is, how honestly the study was conducted, and whether it is clear and understandable can be examined. How opposing ideas were handled can also be analyzed. In another study, we can look at which scientific methods were used, how they were accessed, and what other studies included. I also think the final units are more suitable for this. The SI can be examined, or the social aspects of any scientific study can be evaluated at the end of the unit. Apart from this, we are already engaged in scientific practices, and many students are aware of them, but they are not explicitly discussed. For instance, they realize that they are creating a model or conducting an activity. As they progress to higher levels, they also become aware that they work with data in tables, but what are the characteristics of this data? (Leyla, post-interview)

She thinks that some NOS categories, such as the SI and SP, are easier to integrate because students are more familiar with them. However, teaching SK, theories, and laws proves to be more difficult, especially for younger students, as these concepts require a higher level of understanding. She also points out that students struggle with constructing hypotheses and identifying variables, indicating that these skills need more structured support. Furthermore, she thinks that teaching the AV can be complex, as it requires students to critically evaluate scientific work, which is a skill that develops over time. Overall, teacher Leyla highlights the importance of careful planning and scaffolding when integrating NOS into the curriculum, ensuring that students gradually build their understanding through meaningful experiences. She states her ideas as follows:

> "I think the easiest was the social aspects of science. I know it is quite diverse, but at least some parts of it can be addressed in lesson plans. Another one was SP because these are familiar to students. However, SK, such as theories and laws, was somewhat advanced for them. The definition can be explained, and perhaps at higher levels, the topic can be covered more extensively. But for 5th graders, they were just introduced to these concepts—they only heard about them. This is still important, but it is a bit difficult for them to fully understand. Another category was Brandon's Matrix. They understood it, as I mentioned, through scientific studies. However, they still struggle with changing variables and forming hypotheses… Another challenging category was the AV of science. Some of these are very clear, such as the universality of science and the necessity of objectivity in knowledge. However, I think there are also aspects that students would struggle to understand. This is not an easy category because it requires evaluating an existing study… I believe this is a category that can be developed over time." (Leyla, post-interview)

Finally, the teacher is asked how she feels about herself in terms of teaching NOS after implementing her lesson plans. Teacher Leyla signifies the positive impact of the PD program on her confidence in teaching the NOS. She expresses confidence in their ability to teach the NOS effectively and emphasizes the usefulness of the provided resources in addressing potential challenges. Furthermore, the teacher appreciates the structured approach of the RFN, particularly its visualizations and modelling aspects. She finds that having clearly defined dimensions and sub-dimensions enhances their understanding, allowing them to form a more comprehensive and structured perspective on the NOS. Instead of a fragmented view, the framework provides a holistic representation, making the connections between different aspects of the NOS more explicit. This structured and visualized approach helps her to internalize diverse aspects of science and feel confident in terms of more effective teaching practice.

> "… I have gained confidence in myself. I mean, we already have some of the information you shared with us. If I encounter any difficulties, I can always refer back to them. But right now, I feel like I can teach this. I can say that I am confident in this regard…. In my opinion, the strength of the RFN lies in its visualizations and modelling. The dimensions are clearly defined, as well as the sub-dimensions. As much as possible, the characteristics of these sub-dimensions have been specified, which creates a more holistic picture. Instead of just saying, "This aspect belongs to the NOS, and that aspect also belongs to the NOS," or "Science has these characteristics," it presents them in a structured way, visually represented, and modelled." This makes the picture in my mind much clearer. That's why I think it has been very effective." (Leyla, post-interview)

Leyla's Observation Forms

Leyla's first teaching observation (implementation of the MIX1 lesson plan). Leyla's first observation, done by the researcher for the MIX1 lesson plan, was taught to 7th-grade students. The science topic was molecules. The implementation lasted 40 minutes for one lesson hour. There were 20 students in the classroom.

In the teaching section, the teacher started the lesson by reminding the students of the previous lesson. She opened a PowerPoint presentation and asked, "Do substances consist of only one type of atom, or do different atoms come together to form substances?" "There are only 118 elements that consist of only one kind of atom in nature, so do you think they are suitable for forming all substances?" The teacher showed molecules of water and Hydrogen-2 and asked the same questions again. She used an analogy to show differences by showing Lego pieces. (N_2 and H_2 molecules have the same atoms, while H_2O and CO_2 have different atoms). The teacher explained that elements consist of only one kind of atom, while compounds consist of more than one. She also explained the meaning of molecule. Teacher Leyla distributed a worksheet. In the worksheet, there are 12 molecules. She asked, "how do you classify them?" (based on colors, number of atoms, types of atoms, etc.). She gave 10 minutes and visited all the desks. The teacher continued, "Scientists reached the consensus that elements consist of only one kind of atom while compounds consist of more than one. So, based on this knowledge, how can we classify these molecules?" They classified them as elements and compounds. The teacher provided other examples of classification, such as classification of living things as animals, plants, fungi, and microscopic organisms, to teach the function of classification in science. She emphasized that when scientists made this classification, they obtained the approval of the scientific committee. The teacher reminded students of scientific practices as observation, experimentation, classification, finding evidence, sharing the findings, hypothesis testing,

etc. She continues to ask, “Why do we use models in science?” After taking students’ ideas, she explained that “models are used in science to study very small or very large objects more easily, such as space and cells.” She continued to explain the significance of finding evidence and classification in science. For example, “classification makes it easier to work in science and helps us understand the characteristics of a group. When a new organism is discovered, knowing its classification allows us to determine many of its characteristics." She asked, “you are scientists, and you will construct a new molecule, which issues do you pay attention?” (properties of atoms, previous studies) “why we should consult a science community?” (reliability of studies, dissemination of scientific knowledge). “What criteria do you think the scientific committee will consider when evaluating your classification and explanations?” (our evidence, explanations, consistency, and reporting findings). Finally, teacher Leyla showed Brandon’s Matrix and explained diverse scientific methods that include manipulation and not, hypothesis testing and not. She briefly explained the examples from the history of science and asked, “Which of the examples here does the scientific study we conducted today resemble?" (no manipulation, not hypothesis testing). She completed her lesson by showing some molecules and asked whether they are elements or compounds.

Teacher Leyla followed the lesson plan as it was; she provided more examples given in the lesson plan. She referred all NOS issues stated as objectives. Through question and answer, she tried to make her students active and experience some scientific practices such as prediction, classification, discussion, etc. She managed time effectively. Her teaching score is 34/36.

In her reflection, teacher Leyla shared her experiences about the implementation. She was pleased with her implementation. She explained what was good in the lesson, such as managing time effectively, intense question and answer about NOS, asking all NOS questions stated in the lesson plan, classroom management, etc. Her total score was 46/48.

Leyla’s second teaching observation (implementation of the MIX2 lesson plan). The second lesson (MIX2) observed by the researcher was taught to 7th-grade students. The science topic was pure substances: elements and compounds. The implementation lasted 40 minutes for one lesson hour. There were 6 students in the classroom.

Teacher Leyla started her lesson by reviewing the previous lesson with the question, “What are elements, compounds, and molecules?” She opened a PowerPoint presentation and showed models of them and wanted students to identify each one. Then, she continued her presentation, asking what they know about CERN and what kinds of studies are conducted there. After taking the students’ answers, she introduced CERN to her students. Then asked, "In your opinion, through which communication channels can scientific knowledge be shared?" (Students answered as newspapers, journal articles, etc.). “Where can scientists encounter each other face-to-face?" (conferences, universities, congresses). “Which sources are more reliable or appropriate for sharing scientific knowledge?” (journals, conferences, laboratories, etc.). “Do you think scientists can present the properties of matter based on only one study for exploration? Why? (No, they need more evidence, need to confirm and generalize their results, increase their reliability, etc.). She read texts from the presentation that they had opposite ideas about the particle and teacher asked, “What do you think are the advantages and disadvantages of scientists having opposing ideas?" (They have difficulty in reaching a conclusion as disadvantages), they search more, and they think diverse aspects as advantages) “What are the advantages and disadvantages of working solo?” (higher workload, lack of reliability, needing more time). The teacher read the text from the presentation that scientists make inferences, inquiring about the particles and reaching the conclusion that it can be a new type of matter, different from elements and compounds. The teacher provided an example of the umami taste. Then, she explained the properties of elements with atomic and molecular structure. Then, she asked, “In which ways do scientists reach scientific knowledge?” (modelling, reaching evidence, benefitting from the previous lessons, experiments, hypothesis testing, classification, reasoning, consulting other scientists, etc.). The teacher continued to ask, “So, do you think biology, chemistry, physics, or astronomy use the same or different scientific methods? Does the field itself affect scientific methods or not?” The teacher reminded Brandon’s Matrix and provided diverse examples from the history of science. She continued to ask, “How do scientists find money for their research? (from research centers, TEKNOFEST, TÜBİTAK, universities, governments, etc.). Finally, the teacher asked, “Scientists from different nationalities can work together at a research center, such as CERN. So, what do you think about its effects on countries politically and economically?" (Countries can benefit from the results of the studies, economic development, etc.). At the end of the lesson, the teacher made an evaluation of elements and compounds through a few questions on the presentation.

In her second lesson implementation, teacher Leyla taught science and NOS issues effectively. She referred to all objectives in the lesson plan during her implementation. Also, she referred to scientific methods and political power structures of science. She encourages her students to share their ideas. Since the number of students in the class was low, the students were able to focus better on the lesson. She prepared a PowerPoint presentation for visuals and questions. She managed duration effectively. The students were encouraged to be active only through questions and answers. She made her evaluation only through science-based questions. Her second teaching score is (32/36), which is very good. Her final score was calculated as 44 out of 48.

Leyla's Journals

According to the teacher's seven-week reflection on the implementation of lesson plans in her classroom, she effectively conducted her lesson plans. Each week, a different dimension of NOS was explored and integrated into lesson plans. Teacher Leyla provided so detailed reflection about her implementations. In the first week, it was aimed to teach the aims and values of science. She thought the class went well, as students responded positively to the motivational questions at the beginning, which helped the lesson flow smoothly. They successfully worked on drawing the correct graphs, and there were no major issues during group discussions. By the end, students could evaluate the graphs based on the formula. However, they had trouble using bar charts to represent mechanical energy, as they preferred using numbers to check their work. This showed the need for a deeper look at different scientific models and how they connect. If she were to teach this lesson again, she would have students first draw graphs on their own before working together to finalize the best version. Even though students met the learning goals in the assessment, they struggled with understanding the NOS, as their answers to related questions were unclear. This indicated they needed more exposure to scientific processes and the characteristics of science.

In the second week, it was aimed to teach scientific methods. The teacher reflected that the shift to individual tasks worked well, as students took more responsibility than in group activities. Mentioning CERN sparked their interest, and students were excited to learn more. The connection to a video from sixth grade also helped to keep their attention. However, they had difficulty understanding scientific methods, especially identifying which

one was used in the activity. If she taught this again, she would use multiple-choice questions to clarify their understanding of the scientific method. Most students understood the core scientific concepts during the assessment but struggled with identifying the exact method. After addressing this, they seemed to understand better.

In the third week, the lesson plan incorporated scientific practices. The teacher thought that the lesson was well-received, with students enjoying predicting which phase changes various everyday examples were illustrating. They were also motivated by the Benzene Ring Analogy, and they easily identified which scientific practices were involved in the examples provided. However, when discussing the water cycle, some students initially struggled to connect the answer with phase changes. According to her, this demonstrated how students often relied on prior knowledge that wasn't always aligned with the topic at hand. The lesson would have benefited from allowing students to collaboratively identify which scientific practices were being used, rather than answering individually, which may have resulted in a more inclusive discussion. The lesson was meaningful to the students, especially when they were able to relate phase changes to real-world examples. However, they still found it challenging to identify scientific practices independently without analogies. A more direct exploration of these practices could enhance their understanding.

In the fourth week, the scientific knowledge category of RFN was taught to the students. She reflected that students were able to correctly answer questions about scientific laws, theories, and models, particularly in the context of heat flow. The concept of scientific laws and theories was introduced in the context of heat flow, which made it easier for students to grasp. However, most of the students had not encountered the terms "scientific law" and "theory" before, which led to some confusion. Additionally, their prior knowledge of heat flow was somewhat restrictive, as they were primarily focused on the temperature differences between hot and cold objects. If she were to revise this lesson, she would omit complex terms like thermodynamics for this age group, as they did not resonate with the students. Despite the challenges with some students' motivation and understanding of the different types of scientific knowledge, students were able to successfully model heat flow and achieve the intended learning goals related to the topic. On the other hand, for the teacher, it was hard to teach the scientific knowledge category of RFN. She conveyed her

ideas about her teaching practice in terms of teaching scientific knowledge in the following way:

> "I had a lot of difficulty implementing this lesson plan. When I noticed the students' low motivation and difficulty in understanding the types of scientific knowledge, I resorted to a direct explanation during the exploration phase. I tried to stick to the lesson plan, but since I had to complete the lesson within 40 minutes, I couldn't wait for the students to think and develop more explanations. As a teacher, when the functionality of our lesson plans isn't sufficient, we should make adjustments during the process and prioritize ensuring that students reach the learning objectives at a high level." (Leyla, teacher journal, week 4)

In the fifth week, the SI of RFN aimed to teach students as an NOS objective. Teacher Leyla believed that students were particularly engaged when learning about the stories behind the names of elements. The inclusion of a news report about newly discovered elements helped students understand the connection between scientific discoveries and their social significance. The discussion delved into the political and financial dimensions of scientific research, with students expressing interest in the historical and current tensions between countries like Russia and the U.S. One unexpected result was how deeply engaged the students were in the political and social ramifications of scientific endeavors. If she were to teach this lesson again, she would allocate more time for further discussion, as students had many insights to share but were limited by the time constraints. Overall, students demonstrated a deep understanding of the SI of science, with their responses reflecting a good awareness of how science influences and is influenced by societal factors.

For the final two implementations, teacher Leyla was observed by the researcher. For the sixth week, she reflected that the lesson was completed within the planned time, and students were actively involved in the classification activity. They proposed various ways to classify molecules, which led to a rich class discussion. The NOS was discussed in depth, with students offering multiple responses to questions and evaluating each other's answers. One surprising outcome was the class's high level of engagement and participation, especially since they hadn't been accustomed to such in-depth discussions. If she was to repeat this lesson, she would extend the time to allow for more comprehensive group work, where students could present their classifications and collaborate to refine them. According to her this would encourage more interaction and a deeper understanding of the subject matter. The students achieved the learning objectives, as evidenced by their accurate classifications and thoughtful reflections on the NOS. In the seventh week, she thought that

the lesson proceeded well, with students showing no signs of conceptual misunderstanding. They answered questions related to the NOS with appropriate responses, indicating that they had grasped the content, especially concerning elements, compounds, and molecules. However, due to the low number of students present (it being the last week of school), the discussion was less dynamic than expected. Some students mentioned that individual work allowed them to work more effectively, which seemed to stem from difficulties with group work dynamics. If she was to repeat this lesson with more students, she would use a concept map to visually represent key terms and their relationships, facilitating a deeper discussion and ensuring that any overlooked points could be addressed. Despite the reduced class participation, the learning objectives were met, and the students demonstrated their understanding of the scientific concepts being taught.

As a result, it can be said that teacher Leyla's self-discipline in the implementation of all lesson plans was good. She reflected on her experiences in detail. She generally implemented her lesson plans successfully. Considering RFN categories, she struggled most with the teaching scientific knowledge category of RFN.

Leyla's Group Discussions

Teacher Leyla possessed prior knowledge of some components of the RFN framework and adopted a student-centered approach to science teaching. During the analysis of her reflections shared in the group discussion session of the PD workshop, it became evident that she experienced anxiety about meeting the science objectives provided by the Ministry of Education. Like her group members, Leyla noted that her students struggled with interpreting and drawing graphs, which posed a challenge in achieving both science and NOS objectives. In her initial lesson plan implementations, she could not make explicit connections to NOS, focusing primarily on science content to align with curriculum requirements.

Over the weeks, however, Leyla grew more confident and began incorporating more explicit NOS connections into her lessons. She reflected that this shift significantly improved her students' comprehension of the SP category of RFN, as they interpreted diverse scientific practices from BRH well. Despite this progress, she encountered difficulties teaching the SK

category of RFN. She found the activity in her lesson plans ineffective and even led to misconceptions among her students; for example, some mistakenly believed that all scientific theories and laws were related to the concept of heat. To address these issues, Leyla suggested using a wider variety of examples to illustrate NOS concepts and teaching theories and laws as distinct topics to clarify their differences.

4.2.2.5. Case 5 – Melisa's Teaching *Practice.* *Four* data sources, which are individual interviews, teacher journals, observation forms, and group discussions during the workshops' reflection and discussion sessions, were independently analyzed to examine how Teacher Melisa translated her NOS understanding into her teaching.

Melisa's Interviews

Melisa is asked how she sees herself teaching NOS before the intervention. She thinks that her approach to teaching the NOS is quite basic, primarily relying on verbal explanations rather than engaging, hands-on activities. While she recognizes the importance of providing written materials, when possible, she admits to not using an active or structured method specifically aimed at teaching the NOS. Instead, her approach is more incidental, aiming to expose students to key ideas without deeply integrating them into lessons. This self-assessment highlights a potential area for growth, suggesting that incorporating more deliberate and interactive strategies could enhance students' understanding of the NOS. She shares her thoughts in the following way:

> "I think I am at a very basic level because I usually just mention it verbally in passing. If I have the opportunity in my activities, I find it important to provide written materials so that they can keep them. However, I cannot say that I conduct many activities or use an active method specifically aimed at teaching the nature of science. I only try to spark students' curiosity at certain points, thinking, "Let them hear this, let them know this." Other than that, I cannot say that I actively work on it." (Melisa, post-interview)

After the intervention, Melisa found implementing the lesson plans both exciting and challenging. The excitement came from the enjoyable training sessions, which made her eager to see how the plans would work in class. Overall, the lessons went well, but there were some difficulties. For example, a modelling lesson with 7th graders was particularly tough, and in a crowded fifth-grade class, students struggled to see a demonstration on

friction. There were also unexpected issues, like students not being able to read subtitles in a video. Despite these challenges, the experience was valuable. It helped the teacher think more about problem-solving and adapting to different situations in the classroom. It also showed that teaching isn't just about having a good plan—it's about being flexible and finding solutions when things don't go as expected. She states her ideas as follows:

> "My experiences were exciting because we enjoyed the training sessions—they were engaging and not boring. After creating each lesson plan, I was always curious about how it would work in the classroom. Would it be effective or not? That was exciting. Overall, I think things went well, though there were some challenging moments. For example, I really struggled with a modelling lesson for seventh graders. In a friction experiment with fifth graders, I faced a similar issue as I had with sixth graders before, but it was even harder because the younger class was larger, and many students couldn't see my demonstration properly. In terms of lesson planning, there were no major issues. The plans developed well, and we generally felt satisfied with them. However, external factors affected the experience. For example, in one lesson, students couldn't read the subtitles in a video. The video was great and very useful for my teaching, but if the students couldn't see the subtitles, I couldn't just ignore the problem. This process shaped my approach to teaching. Instead of simply giving up when something didn't work, I started thinking about how to adjust and improve. The challenges were actually beneficial because they reminded me that teaching isn't just about having a well-prepared plan—it's about adapting. Every lesson showed me that reality doesn't always match expectations. This experience helped me grow, making me reflect on how I approach and solve problems in the classroom. That was valuable." (Melisa, post-interview)

Teacher Melisa is also asked whether she thinks teaching RFN categories is possible or not, and which categories are easy, and which are hard to teach. She expresses strong confidence that all NOS categories can be incorporated into lesson plans, emphasizing the dynamic and ever-evolving nature of science education. While curriculum constraints exist, the teacher's perspective and intellectual depth play a crucial role in successful integration. The ability to make connections between daily life, prior knowledge, and interdisciplinary applications significantly enhances the teaching experience. She states her ideas as follows:

> "I think it is possible for each category… Science means daily life, and daily life means accumulated knowledge. Therefore, there is a very dynamic relationship between science, daily life, and school. I think there is an incredible connection between them. That's why science lessons are very suitable for this. But where do we get stuck? How competent is the teacher? What are the teacher's resources? What is the organizational state of the classrooms?"

The ease of teaching certain NOS categories varies. The SI category was particularly smooth to implement, as students had prior knowledge and engaged actively in discussions about scientific institutions, policies, and applications. In contrast, topics related to mass, weight, and buoyancy posed more challenges due to conceptual complexities and time constraints. However, the teacher notes that integrating NOS into lesson planning minimizes

difficulties, as discussions and student participation help drive understanding. A key takeaway from this reflection is that teaching the NOS requires adaptability. While some topics may be more challenging, they can still be effectively taught with careful planning and an open-minded approach. The collaborative nature of PD programs and structured frameworks, such as the RFA, provides valuable support for educators in making NOS more accessible and engaging for students. She communicates her thoughts in this way:

> "…Yes, there is a curriculum, but the curriculum serves as a guide. We are responsible for implementing it, but expanding or adapting it is still in our hands… So, if we can organize ourselves based on our perspective, we see that we can integrate every aspect of the NOS, especially within the FRA…. The category that flowed like water was the SI aspects. It was a single-period lesson, which was a huge advantage. The students had prior knowledge; it was a familiar topic to them. Things like CERN, Türkiye's CERN membership, what the products of scientific knowledge are, how they relate materially, and what political power means. … Both I and the students enjoyed it. …. But apart from that, I don't think any aspect of the NOS was particularly difficult. Each had its own beauty and ease. The difficulty disappears when it is embedded into the lesson plan. In the classroom, we go through it, we talk, and the students contribute well. I never experienced a situation where I introduced an aspect, and the students had no clue about it, giving no response at all. In fact, the lesson I was most concerned about in this regard was the one where we discussed law, theory, and models with fifth graders. They had no prior background on the topic. But even they approached it quite well. ..." (Melisa, post-interview)

The teacher is also asked how she felt about herself in terms of teaching NOS after participating in the PD program. She expresses increased confidence and a more structured approach to lesson planning. Previously, her strategies were more limited, but now she feels more competent in implementing well-organized plans, which has strengthened her ability to convey the subject effectively. While she acknowledges that time constraints sometimes prevent them from covering topics as deeply as she would like, she does not feel inadequate in her teaching. The program has contributed to her teaching proficiency by reinforcing problem-solving and adaptability skills. As a result, teacher Melisa highlights the program's positive impact, demonstrating how structured training can enhance both confidence and instructional effectiveness as below:

> "My confidence has increased a bit, and I feel a little more competent, mainly because I have seen and tried to implement plans. Before, I was more verbal… Yes, I had awareness and tried to convey it to the students in class, but the strategies I applied were more limited. Now, I have a clearer understanding of where each element fits within a structured plan, what to do where, and how to connect concepts. Didn't we prepare five plans in groups? And we reviewed approximately 15-20 plans. That gave me strength, a sense of "You can do this." So, I feel more secure in conveying the subject." (Melisa, post-interview)

Melisa's Observation Forms

Melisa's first teaching observation (implementation of the MIX1 lesson plan). Melisa's first lesson (MIX1), observed by the researcher, was taught to 6th-grade students. The science topic was density. The lesson lasted 80 minutes for 2 hours. There were 27 students in the classroom.

In the teaching section of the lesson plan, teacher Melisa started to lesson plan by reminding previous lesson and opened the story of Archimedes' Eureka moment video. She described Archimedes and explained the aims of the lesson. In some part of the video, she stopped the video and attracted students' attention with questions. She distributed worksheets and asked the question, "What was the problem that Archimedes had to solve? (the construction of the ship, the ability of the ship to float) What methods do you think Archimedes might have used to solve this problem? (making predictions, doing experiments, trial and error, gathering information, testing materials, etc.) Teacher Melisa emphasized that there could be problems in studies conducted without testing. She gave the example of "Vasa Stockholm". The video on the history of science attracted students' attention. Then, she wrote on the board "Law of Buoyancy – Archimedes' Principle". She explained different types of scientific knowledge, specifically laws. Then, she asked how Archimedes' law of buoyancy has contributed to humanity (the production of better and different ships, the invention of inflatable sails, the development of maritime tourism, etc.).

In the second lesson, she brainstormed through the question "What factors affect buoyancy and sinking?" and wrote their answers on the board (mass, volume, gravity, the type of material, etc.). She reminded differences between mass and gravity and opened a video about density from the EBA. In the video, a monkey throws the wheat into the water to separate it from the sand and collects the floating wheat. Teacher Melisa explained the meaning of a hypothesis and asked her students to construct their hypotheses for different materials that have the same mass but different volumes. Students wrote their hypotheses on the activity sheet. In the activity sheet, there was a table for students to record their observations on the mass, volume, and state in water of the materials wood, iron, and plastic. The teacher tested each material on the smart board, and they discussed their hypothesis. The same activity was done for the same materials with the same volume but different

masses. Then, a video about the definition of density was shown, and students reached the conclusion that both mass and volume affect the density of matter. The teacher explained that density is a distinguishing characteristic of materials. Finally, the teacher opened the Benzene Ring Heuristic visual and explained scientific practices. She asked students to determine which scientific practices they used during the lesson as scientists (experiments, prediction, data, observation, and discussion).

It can be said that teacher Melisa internalized NOS teaching. She made good connections to NOS. In each section of the lesson, she referred to NOS with questions. She encouraged her students to share their ideas, feel themselves as scientists, experience diverse scientific practices, etc. The duration was suitable. Also, she used different teaching methods such as videos and simulations. However, the teacher did not refer to all objectives about scientific methods, such as explaining different scientific methods, exemplifying studies based on observation and experiments, etc. In a similar way, there were limited interactions among the students. Finally, the teacher made only a NOS-based evaluation at the end of the lesson. Thus, her teaching score is 34/36.

Teacher Melisa reflected on her ideas about her implementation at the end of the lesson. She found herself successful in classroom management, finding solutions to encountered problems, emphasizing NOS, and being able to follow the flow. She suggested developing herself for the evaluation part of the lesson and checking the materials before the lesson. Her total score was calculated as 66/48.

Melisa's second teaching observation (implementation of the MIX2 lesson plan). Melisa's second implementation was observed for the 7th-grade science topic on molecules. There were 32 students in the classroom. The lesson lasted 4o minutes, one lesson hour.

In the teaching section, the teacher started to group students and opened a PowerPoint presentation. In the presentation, there were pictures of a succulent logo. The teacher asked, "What do you do with logos in daily life? Is there anyone who has never made a logo in their life? What was used to create this succulent made from a logo? What might LEGO pieces resemble? Imagine and try to create a succulent piece using playdough." The teacher wrote the purpose of the lesson on the board and wanted them to work in groups. She gave them

15 minutes for the group activity. She visited each group and remembered that they would not do succulent itself, instead they model its particles. She continued, “If the LEGO company had hired you, what common feature would you define?” She wrote answers on the board (grip point, fixation point, snap-on/Snap-fit, the pieces themselves). The teacher continued her lesson by asking, “What is the smallest particle? (atoms) What is the relationship between atoms and logo particles? The teacher made a good connection between logo particles and atoms. Each group presented their models, and the teacher asked what they modelled, considering colors and size. Some groups modelled sub-particles of atoms. The teacher asked, “If you were part of a group of scientists and had the knowledge about atoms, how would you model atoms to introduce people? What common features were similar to each other in your models?” (Layers, nucleus, electrons). “So, as a community without reaching a consensus, could you construct a model for atom? If you have different models, how did you share your models with others?” (You need to reach a consensus; thus, you should look for common points in your models, such as showing sub-particles, nucleus, using different colors, using circular shapes for standardization, etc.). She emphasized that in reality, scientists do the same things: they develop models, they discuss their findings, when they reach consensus, they share their findings, if they do not, they continue to work. The teacher wrote some formulas of compounds and wanted them to construct models of these compounds (H_2, $C_6H_{12}O_6$, CO_2, and H_2O) as groups. They presented their models and asked questions about the number of atoms, the types of atoms, and the types of molecules. Finally, the teacher opened the visual of Benzene Ring Heuristics and asked which practices they did during the lesson (modelling, explanation, prediction, observation, classification). She did evolution in both science and NOS objectives.

In her teaching, Melisa’s classroom management was good. She effectively conducted the group activities. However, since there were more students in the classroom, it took more time for each group to present their models to others. Nevertheless, she finished her lesson as planned in the lesson plan. She made good explanations and connections about the NOS. Thus, her teaching got 36/36 points.

After the implementation, she reflects that she felt anxious about time management. She found that her group activities were effective and beneficial for understanding the scientific practices. Her total score was determined as 48/48.

Melisa's Journals

During the first five weeks of lesson implementation, the teacher's reflections demonstrate a dynamic and evolving teaching process. In Week 1, the focus was on the aims and values of science. The lesson flowed smoothly, with high student engagement, unexpected high participation, and effective use of prediction exercises. The teacher successfully integrated the NOS elements but felt the need to make them more visible and tangible. Although students struggled with the second exit ticket question, their responses in other areas indicated a stro grasp of the learning objectives. Week 2 introduced scientific methods, emphasizing the importance of variables and research questions. While students were actively engaged in discussions, time constraints prevented a deep exploration of key concepts. Despite this limitation, students' responses to activity sheets showed promising understanding. The lesson's relevance to daily life made it meaningful, although more structured reinforcement of NOS principles could enhance comprehension. Week 3 focused on scientific practices, highlighting how scientists generate knowledge through various means. The lesson structure prompted fruitful discussions, but hands-on activities led to unexpected distractions and confusion, particularly with material properties. While classification activities worked well, conceptual misunderstandings persisted. The teacher acknowledged the need for better material selection and stronger instructional scaffolding to ensure clarity. In week 4, scientific knowledge types were introduced through multimedia resources. Although the initial engagement was positive, an English-language video with Turkish subtitles posed comprehension challenges. Students' assessment responses indicated difficulty in distinguishing scientific knowledge types, highlighting a need for a more interactive approach, such as guided note-taking or scaffolded discussions. These weekly reflections illustrate the teacher's growing awareness of both pedagogical strengths and areas needing refinement. Throughout the weeks, she demonstrated adaptability by adjusting her instructional strategies in response to student needs and classroom realities. Her reflections also suggest a commitment to improving NOS integration, balancing content delivery with the development of scientific thinking skills. Teacher Melisa shared a photo of the students' responses to the questions in the evaluation section in their journal. It is shown in Figure 4.32. below.

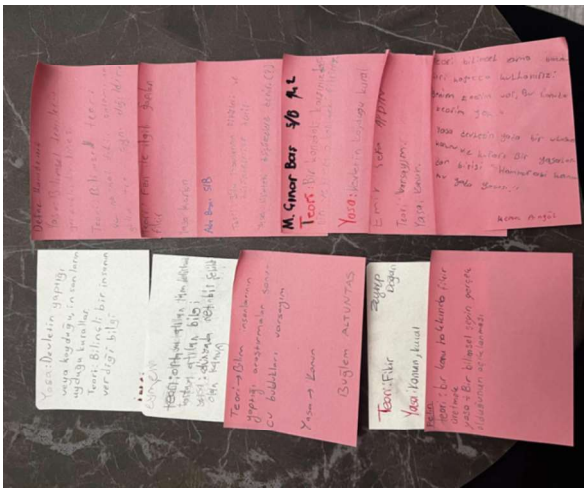


Figure 4.32. Melisa's photo from the implementation of the fourth lesson plan.

Week 5 addressed the social and institutional aspects of science, featuring discussions on CERN. The pre-existing interest and knowledge of students facilitated in-depth discourse. While students were eager to learn more, they struggled with applying scientific advancements to different domains. The structured reflection at the lesson's conclusion confirmed their understanding of key concepts, making the lesson both meaningful and effective. Teacher Melisa reflected her thoughts about the effectiveness of the lesson in this way:

> "I believe the students achieved the learning objectives. Both the responses given by those who participated in class discussions and the answers written on their activity sheets allowed me to clearly see their understanding of the topic. The question they struggled with the most was the one about transferring scientific developments to different fields. On the activity sheets, they often wrote down the examples I had provided. Aside from that, when I asked at the end of the lesson which components we had addressed on the Wheel of the SI Aspects of Science displayed on the board, they were able to answer clearly. I think the lesson was meaningful for the students because participation was high, and by the end of the lesson. A news article about an international organization and membership in that organization was an effective tool to address the SI aspects of science. Through this article, we had the opportunity to discuss various components, and I believe we deepened their understanding of the topic with additional examples such as national organizations and the science fair process, where students prepare projects." (Melisa, teacher journal, week 5)

In the final two weeks, the teacher aimed to integrate at least two NOS categories per lesson. The researcher observed these two weeks. In week 6, the lesson proceeded smoothly despite an initial issue with video readability. The teacher managed the situation effectively, though recognizing that in a different classroom, this might have been more disruptive. A conceptual roadblock occurred when students struggled to differentiate mass and weight,

affecting time allocation for subsequent topics. Nonetheless, student engagement and responses suggested that learning objectives were largely met. Week 7 further built on these strategies, likely incorporating refinements based on prior experiences. Given the teacher's ongoing reflection and adaptation, it can be inferred that adjustments to instructional materials, questioning techniques, and student interaction strategies played a role in enhancing comprehension. The teacher's ability to recognize challenges and proactively adjust instruction highlights a reflective teaching approach, ensuring continuous improvement in delivering NOS concepts effectively.

Melisa's Group Discussions

Teacher Melisa shared her experiences implementing lesson plans during the reflection and discussion sessions of the PD workshops. Prior to the intervention, she was already familiar with some categories of the RFN framework. As a result, she emphasized teaching key scientific concepts, such as identifying variables and conducting experiments, in her lessons before the workshops began. This approach equipped her students with foundational knowledge of certain NOS-based concepts, which enhanced their engagement in classroom activities. Melisa's students participated actively in these activities, demonstrating enthusiasm and curiosity.

Analysis of her reflections revealed that Melisa did not limit her lesson plan implementation to a single class; she applied the plans across multiple classes to assess their versatility. This approach allowed her to provide detailed feedback on the effectiveness of the lesson plans, highlighting both successes and areas for improvement. For example, in a lesson plan targeting the SP objective, Melisa aimed to teach the particulate nature of matter by demonstrating the compression of substances in syringes. However, the selected materials and simulations were not effective, leading to misconceptions among students about the behavior of particles, which prevent explicit NOS connections.

Melisa's experiences are similar to those of her group members, particularly in the challenges of teaching the SK category to 5th-grade students. She noted that her students struggled to grasp distinctions within scientific knowledge, such as differentiating between theories, laws, and models, due to the abstract nature of these concepts at their grade level.

To address these difficulties, Melisa suggested clearer guidelines for selecting materials to avoid misconceptions and enhance the effectiveness of simulations in future lessons.

4.2.2.6. Case 6 – Zeynep's Teaching Practice. Four data sources, which are individual interviews, teacher journals, observation forms, and group discussions during the workshops' reflection and discussion sessions, were independently analyzed.

Zeynep's Interviews

In her pre-interview, teacher Zeynep is asked how she sees herself teaching NOS. She thinks that a student-centered and inquiry-based approach can be a way to teach NOS. She emphasizes that science education should be more than just memorization; it should foster curiosity, problem-solving, and active participation. By encouraging students to understand why they are learning a particular concept and allowing them to pose problems and find solutions can provide students to learn NOS. She highlights the importance of active engagement, reinforcing the idea that learning is most effective when students take ownership of the process. It can be concluded that Teacher Zeynep thinks that NOS is more about teaching methodology, and she refers to NOS by making students active in her lessons. She puts forward her ideas in this manner:

> "… If the NOS is what I have in mind, then this has always been my goal. I want to create an environment where, when children come to science class, they don't feel like they are just attending a lesson but rather entering their own laboratory, their own scientific space, their own workspace. I care about this because I want them to come to class knowing not only the topic we will cover, but also why they need to learn it. E.g., if they are going to learn about density, they should understand why it is important, present their own problem, and generate ideas to solve it. In other words, I care about this because I want them to be fully engaged in the lesson, take ownership of their learning, and reach a goal by teaching themselves." (Zeynep, post-interview)

After the intervention, teacher Zeynep is asked about her experiences with the implementation of the lesson plans they developed. She highlights several challenges in implementing the NOS in her classroom practices. One of the main difficulties is balancing the NOS with the required science curriculum within the limited time available. Because she works in a private school, she is expected to cover some issues with some resources. When she prioritizes NOS issues, she struggles with adjustment. Thus, covering both the provided resources and NOS concepts can sometimes make lessons overwhelming or even

uninteresting for students. She needs a broader curriculum adjustment to effectively integrate NOS into science education. Another major challenge is understanding and teaching complex scientific concepts such as laws, models, and theories. She admits struggling with these topics both as a learner and an educator, especially in terms of integrating them into lessons. She states her ideas as follows:

> "Implementing the NOS in some classrooms can create challenges in terms of classroom management. … I think the time constraints imposed by the curriculum can make it difficult to cover both science achievements and NOS objectives simultaneously. We may not always have enough time to complete everything. Additionally, the resources provided by my school also play a role—these resources need to be covered, and the learning objectives must be met. When we also incorporate elements related to NOS, it can sometimes become boring for students. I think there is a need for a general adjustment in this regard; we might have to prioritize one over the other. Doing everything at once can be quite challenging… I think I couldn't fully grasp the scientific method and methodological rules. My mind is still stuck on that; I can't seem to remember them. But in my opinion, learning and teaching concepts like theory, law, and model is the most difficult. I also struggled a lot with integrating them." (Zeynep, post-interview)

Teacher Zeynep is asked whether teaching all RFN categories is possible, and which categories are hard and easy to teach. She acknowledges that for each RFN category, an objective can be constructed, but each category is not suitable for each scientific issue. She thinks that the curriculum includes learning outcomes that address each NOS category, but a well-structured curriculum, categorizing NOS aspects effectively from 5th to 8th grade, would enhance students' engagement with NOS categories. By incorporating these categories, students would gain a deeper understanding of the scientific process, which is essential for activities like conducting scientific research, participating in TÜBİTAK projects, or competing in STEM Olympiads. Without this structured integration, students might struggle to grasp the purpose behind their work, how they conduct it, or its broader impact on humanity. For teacher Zeynep, a significant challenge identified is the constraint of lesson hours. Teaching both NOS and science content simultaneously within the current time allocation appears difficult. She suggests potential solutions, such as adding a dedicated lesson hour for NOS activities or increasing overall science lesson hours. Additionally, teacher Zeynep struggled with learning and teaching scientific methods and scientific knowledge categories of RFN. She puts forward her ideas in this manner:

> "I've realized that there can be a learning outcome for each RFN category, but each learning outcome is not suitable for the science topic for integration. If a proper curriculum is designed and categorized correctly, students from 5th grade to 8th grade can engage more actively with more categories of science. Right now, we expect students to conduct scientific studies, participate in TÜBİTAK projects, or join STEM Olympiads. However, while we have these expectations, students may not be fully aware of what they are doing, why they are doing it, how they are doing it, whether they are contributing to humanity, or which goals and values guide their actions. If we properly integrate the categories of RFN, students' awareness will increase… I think I couldn't fully learn the scientific method. My mind is still stuck there—I can't recall them. Also, I believe the most challenging part is learning and teaching concepts theory, law, and model. I also found it very difficult to integrate them." (Zeynep, post-interview)

Finally, teacher Zeynep is asked how she feels about herself in terms of teaching NOS and the effect of the PD program on her teaching practice. She believes that the PD program had a significant influence on her science teaching approach, particularly in fostering a deeper connection between students and the NOS. One major impact noted is the shift in student engagement, especially regarding their perception of science in everyday life. The common student question, "How will this be useful in real life?", has become less frequent, as students have started thinking more like scientists. Some students, particularly those actively participating in class, now express ideas such as "If I were in this situation, I would do this differently," indicating a more analytical and investigative mindset. She suggests that the program has encouraged students to approach scientific problems with a more inquisitive and proactive attitude. Additionally, she believes that this increased awareness could potentially influence her students' future career choices, making them more inclined toward scientific fields and project-based learning. Despite these positive changes, the participant acknowledges personal limitations in fully integrating the NOS into teaching. While the program has sparked interest and awareness, they still feel the need for further development. The realization that effective teaching requires a thorough understanding has led to a more proactive approach to professional growth, such as actively seeking and reading academic articles related to the topic. This self-reflective attitude suggests that the program has not only impacted teaching practices but also fostered a continuous learning mindset. She states her ideas as follows:

> "I still don't think I am fully competent. But now, whenever I come across an article or a paper on this topic, I make an effort to read it so that I can use it more effectively. To teach something well, you first need to learn it really well. When I try to apply something I have just learned, I still have shortcomings, but I want to read more about this topic. In other words, I've started to develop an interest in it—I can say that." (Zeynep, post-interview)

Zeynep's Observation Forms

Zeynep's first teaching observation (implementation of the MIX1 lesson plan). Teacher Zeynep implemented the MIX1 lesson plan to 6th-grade students. The science topic was density. The lesson lasted 80 minutes for 2 hours. There were 19 students in the classroom.

In the teaching section of the observation form, the teacher started the lesson, reminding the students of the topic they covered in the previous class (density) and explaining the aim of the current lesson. She tried to spark curiosity in a way that would grab the students' attention. However, the class wasn't quite ready to start, and they asked numerous meaningless questions. The teacher patiently answered all of them, but this also distracted from the focus on the topic. The teacher showed the video about Archimedes. She asked questions like, "What was Archimedes asked to do? How might Archimedes have solved the problem?" to guide the students to pay closer attention to the main points of the video. Rewinding the video for unclear parts also helped clarify the content. The teacher, without answering the questions, wrote all the students' ideas on the board (which was not mentioned in the lesson plan). This part was quite successful, as despite the students' side conversations, they expressed some good ideas (e.g., "calculating the ship's density, putting air inside some objects, lubricating the ship, balancing the load inside the ship," etc.). The teacher's patience in asking for all the students' ideas was commendable. The teacher wrote all the ideas clearly on the board and used drawings to make them more understandable. In terms of the flow of questions, the teacher followed a nice progression, trying to make connections to the NOS (e.g., "What steps did Archimedes go through in the video? If you were to conduct a scientific study, would you focus on something from daily life? What would you do if you thought like a scientist?"). She also related SPs such as the real world, models, and experiments, as well as scientific goals like benefiting humanity and the importance of repetitive testing. She tied the topic back to density and reminded the students of the golden crown story. "How would you determine if the crown is made of gold? How might the king have figured it out?" (This example was not in the lesson plan.) This was a good way for students to think about density, but trying to gather all students' ideas led to some time loss. The teacher's reminder of the density formula (d = m/v) using the heart model method was effective for establishing connections. The teacher then refocused on the

question in the video: "At which stages did Archimedes design the ship? (Experiments, creating models, building a prototype, trial and error, etc.) What contribution might Archimedes' law of buoyancy have made to humanity?" (It increased the functionality of buoyancy.)

In the second lesson, the teacher stated the aim of the lesson and told the students that, like Archimedes, they would design a ship in groups, which excited the children quite a bit. The teacher opened the simulation on the board and showed a few examples. The students quickly started to group up and combine their desks. While the teacher introduced the simulation, the students, being focused on grouping, did not fully grasp what they would test in the simulation or the relationship between hypotheses and the simulation. Meanwhile, the teacher tried to remind the students of the concepts of hypothesis, dependent, independent, and controlled variables. Most of the students did not remember the concept of a hypothesis. The teacher provided definitions and gave multiple examples related to dependent, independent, and controlled variables (e.g., "Iron sinks in water") and encouraged the students to discover them through questioning. Writing the examples on the board and offering different ones (e.g., "When mass increases while volume is constant, density increases.") made sense. However, the example might have caused a misconception for the students about the relationship between mass and volume. (Density is a distinguishing property of materials, and under certain conditions, as the mass of a material increases, its volume increases, so density remains unchanged. This might have made it harder for the students to grasp the idea that the density of 1 gram of iron and 100 kilos of iron is the same.) Instead, examples like: "If the mass of an object increases, the volume also increases in the same proportion, so the density remains unchanged /changes /increases /decreases," or "If the volume of an object increases, its mass also increases, so the density remains unchanged/changes/increases/decreases," might have been more beneficial. This is because the students developed similar hypotheses and, when testing them in the simulation, could not maintain the volume constant when increasing the mass of the same material.

In the group activity, although the students were noisy, some students from each group tried to generate ideas. The teacher visited all the groups and tried to answer their questions. The time given for group work was appropriate. Then, she asked one representative from each group to explain their group’s hypothesis and test it in the

simulation. She helped them test their hypotheses in the simulation. She suggested that some representatives modify their hypotheses and allow them to develop their hypotheses independently. She asked all the groups about their hypotheses and variables. However, due to behavior problems, the teacher only worked with the student at the board and was not able to evaluate what the groups did collectively. Showing contradictory situations in the simulation and asking what caused them was a good approach to eliminating misconceptions (e.g., "When we add a substance to water, does the water level rise according to the total volume of the substance or just the submerged part?"). Since the groups did not listen attentively, this part took too much time, and the evaluation section was not completed.

The positive aspects of the lesson included the teacher's control over the lesson and its flow, as well as the appropriateness of the lesson plan in terms of teaching scientific practices and methods. The teacher actively engaged the students through intensive question-answer sessions and a group activity. Additionally, the teacher moved around the groups, providing clarifications for students who had difficulty understanding, and used various materials (video, simulation, whiteboard) to diversify the lesson. The teacher's effort to give everyone a chance to speak and the focus on the NOS were also key strengths of the lesson. The video and simulation were engaging, and the teacher’s meaningful examples regarding hypotheses and variables, along with their positive, patient attitude, stood out. However, there were areas for improvement. The teacher could have refrained from answering questions that distracted students from the main topic. There could have been more emphasis on classroom rules, and the teacher could have been firmer in enforcing them. In terms of time management, the introduction could have been shorter, and instead of answering every question from each student, the teacher could have moved the lesson forward by allowing at least one student to answer. Also, at the beginning of the video, it would have been helpful to highlight the key points to focus on and explain the relevance of the video to the topic. Explaining the concepts of hypotheses and variables before introducing the group activity could have helped students focus better. Providing a worksheet with example hypotheses and variables could have been useful in helping students demonstrate the experiments they designed on the whiteboard. Finally, the teacher was unable to complete the last part of the lesson due to time constraints, and better time management could have ensured that the content fit the planned duration. Her teaching score was calculated as 26/36.

In the reflection section of the lesson plan, the teacher shared her ideas that she had difficulty in classroom management and time management but tried to emphasize NOS effectively. She also stated that she could not understand whether her students comprehend science and NOS issues due to time constraints. Her total score was determined as 34/48.

Zeynep's second teaching observation (implementation of the MIX2 lesson plan). Teacher Zeynep implemented her lesson plan to 5th-grade students for the topic of expansion and contraction. The implementation lasted 80 minutes, 2 lesson hours. There were 12 students in the classroom.

The teacher started the lesson by showing a closed jar and asked, "I wanted to open the jar to make pickles, but the lid did not open. Is there anyone who can open it?" She let a few students try to open the lid. A student could open it. Then, teachers asked, "I wasn't strong enough to open the lid. So, what can I do?" The teacher wrote all the answers on the board (holding the jar under hot water, etc.). She left the jar on the radiator and continued to ask, "If a ring is too tight on our finger, what can we do?" Then, she tried to open the jar, and asked how it opened. What is expansion? How does the matter expand? What is the difference between heat and temperature? The teacher explained how expansion and contraction occur due to the effect of heat. (When substances absorb heat, the energy of the particles increases, and the spaces between the particles widen, thus causing expansion.) The teacher opened a simulation about the expansion. In the simulation, students tried to pass balls through narrow rings by either heating or cooling them. Then, the teacher asked, "What comes to your mind when I say hypothesis? She explained that hypotheses are statements that predict the results of a scientific investigation, essentially assumptions. Before conducting an experiment, scientists formulate predictions about its outcome, which we later test to see if they are accurate. Teacher Zeynep provided example hypotheses related to expansion and contraction (e.g., when a metal ring is heated, its volume increases, the ball expands in hot air, a crushed ping pong ball expands in hot water). The teacher asked "how we test hypothesis? what is the meaning of variables? For example, how can we test the hypothesis that the amount of heat affects the final temperature of a substance?" (by heating identical substances with heaters of different sizes for the same amount of time and then comparing their final temperatures). In order to make sense, the teacher drew the experimental setup on the board and determined the variables. She emphasized that there is

no need to conduct an experiment for each scientific study; some studies are based on observational methods.

In the second lesson, the teacher opened the same simulation again and wanted students to construct and test their hypothesis. Students explained their experiments. The teacher guided them while they were testing their hypothesis. Afterward, the teacher opened a video about expansion on YouTube. She asked, “What happened in the video? Can you give examples to expand on it from daily life?” (milk overflowing, the functioning of thermometers). After making an explanation, the teacher asked, “How does the expansion of liquids make our lives easier?” (taking precautions to prevent power lines from breaking, helping to prevent train accidents). She watched videos about the expansion of liquids and gases from the EBA for the students. In the elaboration part, students classified daily life examples as expansion and contraction. Finally, the teacher opened an evaluation chart on the board. This chart included different scientific practices, and the activities students had done throughout the lesson. The teacher asked the students to mark which scientific practices they experienced during these activities. They discussed and marked which scientific practices they experienced. There were also some evaluation questions that required placing the appropriate words in the blanks, but there was not enough time to implement them.

It can be said that teacher Zeynep felt more prepared to implement this lesson plan. She was able to integrate the NOS issues into the science subjects effectively. The teacher adhered to the lesson plan's flow. The students were engaged actively through questions and answers, and by allowing them to try different experimental setups in the simulation. Since there were plenty of examples in the elaboration section of the lesson, not being able to complete the evaluation part wasn't a major issue. Therefore, the teacher’s teaching score is 30/36.

In the reflection section, the teacher assessed her own teaching. She was pleased with the lesson implementation because she had a strong command of the lesson plan's flow, and various teaching materials were used. Also, students participated well in the class. Her total score was determined as 42/48.

Zeynep's Journals

Analyzing the teacher's journals over the course of seven weeks indicated a dynamic and evolving approach to lesson planning and implementation in the classroom. In week 1, the focus was on the aims and values of science. The storytelling approach proved to be highly engaging for students, making the lesson feel like a game. This autonomy allowed each group to concentrate on its tasks independently. However, the activity took longer than expected, leading to slight timing issues. The students demonstrated their understanding through their explanations of the materials they created, recognizing their mistakes through trial and error. Although the integration of the NOS was not fully realized in this first attempt, the teacher expressed confidence that it would develop over time. Week 2 focused on scientific methods. However, the teacher could not implement this lesson plan. In Week 3, the emphasis was on scientific practices. Students exhibited misconceptions at the beginning, but once these were identified, they became more eager to correct them, improving the lesson flow. A technical issue with the printer meant students had to write notes manually, which slightly disrupted the plan. Despite this, the excitement of discovery was evident, and students actively engaged in classification, observation, and experimentation. The teacher realized that scientific practices were already being implemented naturally and decided to be more deliberate in structuring them going forward. Week 4 introduced scientific knowledge, with students conducting observations on heat transfer and formulating social theories. However, they struggled with differentiating between laws and theories based on a provided visual. A simpler visual aid was suggested as an improvement. The students' active participation in the evaluation stage confirmed their comprehension, although the abstract nature of the lesson led to some confusion. Integrating this category with other concepts was deemed challenging but valuable. In Week 5, the focus shifted to the social and institutional aspects of science. Students engaged with experimental videos, analyzing whether a single attempt could yield accurate results. While some students relied heavily on video demonstrations, leading the teacher to consider a more hands-on approach for future lessons, their ability to think like scientists was evident. However, variations in student preparedness across different classes affected learning outcomes, highlighting the need for differentiated instruction.

During the last two weeks, the lesson plans aimed to incorporate multiple categories of the nature of science. These lesson plans were observed by the researcher. According to teacher Zeynep, in week 6, students showed curiosity and engagement, but classroom management proved to be challenging due to increased noise levels in group activities. The teacher identified that a more structured, individual approach might work better. While some students reached the learning goals through active participation in evaluations, the heterogeneous classroom structure limited the overall impact. Despite this, the teacher found integrating multiple scientific categories enjoyable and effective for developing students' NOS understanding. She reflected her thoughts in this manner:

> "The students were curious, they made an effort to participate, and the categories related to the NOS excited them. Classroom management was challenging. Some students exhibited unexpected behaviors I would keep the introduction shorter. Having students work in groups increased classroom noise, so I would conduct this activity as an individual task instead. I believe the students who participated in the lesson achieved the objectives. They demonstrated their understanding by actively engaging in the assessment questions. Due to the structurally heterogeneous nature of the class, I do not think I was able to make a meaningful impact on the entire group. I really enjoyed integrating this topic. I believe it was a great activity for helping students develop their ability to assess their knowledge and enhance their inquiry skills." (Zeynep, teacher journal, week 6)

In week 7, students demonstrated knowledge retention by connecting prior concepts to new discussions. The class was lively and interactive, though an unexpected event (the unintended opening of a sealed jar) momentarily disrupted the lesson's flow. The teacher realized that omitting certain elements, such as Brandon's matrix, could improve lesson clarity. By the end of the lesson, students had reinforced both their conceptual understanding and their grasp of the NOS, as evidenced by their contributions in the evaluation activity. While the teacher still felt there was room for improvement in applying these concepts fully, they were optimistic about fostering scientific awareness in students through indirect integration in future lessons.

Teacher Zeynep did not provide detailed information about her experiences in her journals. She implemented all lesson plans except for the lesson plan on the scientific methods category of RFN in the second week. When comparing the teacher's reflections with classroom observations from the sixth and seventh weeks, it can be said that she generally focused on the positive aspects of her lessons. However, her reflections lacked evidence, which made it difficult for her to evaluate herself objectively and improve her lessons in this regard.

Zeynep's Group Discussions

During the reflection and discussion sessions of the PD workshops, Teacher Zeynep shared her experiences implementing lesson plans. Working in a private school with access to better resources and smaller class sizes, she effectively conducted group activities in several of her classes. For instance, unlike her group member, Teacher Beren, who faced challenges with large class sizes, Zeynep successfully implemented her AV lesson plan. Her students enjoyed this lesson and creatively designed diverse experimental setups to explore friction force, demonstrating engagement and critical thinking. Similarly, her SP lesson plan was highly effective, as she skillfully managed classroom discussions, ensuring all students had opportunities to contribute and deepen their understanding of SP. Interestingly, Zeynep deliberately avoided teaching the SK category of the RFN. She felt anxious about addressing topics not explicitly mandated by the Ministry of Education's curriculum, fearing that her students might question the relevance of content not covered in standardized exams. She perceived the SK category, which includes concepts like the distinctions between theories, laws, and models, as too theoretical for her students. As a result, she only referenced SK concepts nominally, without delving into their deeper implications. This approach highlights the significant influence of teachers' beliefs and curriculum constraints on science instruction, as Zeynep prioritized aligning her teaching with perceived expectations over fully integrating NOS. She suggested incorporating more practical and abstract concepts related to diverse aspects of NOS.

4.2.2.7. Summary of the Teaching Practice of the Cases. Teacher Aylin initially felt inadequate in teaching NOS due to limited knowledge and examples, relying on repetitive scenarios (pre-interview). Post-PD, she found the program a valuable warm-up, noting improved student engagement, though 6th graders struggled due to behavioral issues (post-interview). She integrated NOS through inquiry-based questioning (e.g., "How do scientists distinguish matters?"), emphasizing real-life connections and reliability of scientific studies, as seen in her MIX1 observation (34/36). In MIX2, she used storytelling and TLM visuals to teach elements and compounds, encouraging scientific thinking (32/36). Journals show she faced challenges with scientific methods (Week 2), adapting by using prior knowledge reminders. Aylin's practice evolved to foster curiosity, though she noted needing more time

to internalize RFN categories, often relying on question-answer formats rather than group activities.

Teacher Beren initially focused on basic NOS aspects like universality and falsification, avoiding technical hypothesis testing (pre-interview). Post-PD, she actively integrated NOS, noting increased student engagement through discussions mimicking scientific debates (post-interview). She taught NOS using inquiry-based questioning (e.g., "Do scientists do this too?") and simulations, as seen in MIX1 (32/36), though NOS emphasis was often at the lesson's end. In MIX2, she used Brandon's Matrix and real-life examples (e.g., expansion in hot water), scoring 34/36. Journals reveal challenges with scientific methods and knowledge (Weeks 1–4), due to students' cognitive levels and classroom size, addressed by simplifying visuals like BRH. Beren's practice encouraged thinking like scientists, though time constraints limited deeper NOS exploration, and she sought more structured discussions.

Teacher Deniz felt inadequate in NOS teaching pre-PD, lacking practical experience from her university course (pre-interview). Post-PD, she struggled with scientific knowledge (SK) and methods (M), feeling the need for more knowledge and practice (post-interview). In MIX1, she taught molecules using models but skipped key analogies, limiting NOS depth (24/36). In MIX2, she improved, using group activities and BRH to teach scientific practices (30/36), though explanations remained limited. Journals show she emphasized inquiry through activities (e.g., parachute modelling, Week 3), but struggled with SK and M due to abstract concepts, missing the SI lesson (Week 5). Deniz's practice improved with structured activities, yet her reflections lacked objectivity, indicating a need for deeper NOS internalization and clearer examples.

Teacher Leyla initially struggled to allocate time for NOS due to curriculum constraints, integrating it sporadically (pre-interview). Post-PD, she gained confidence, using structured questions and discussions to teach NOS, enhancing student engagement (post-interview). In MIX1, she taught molecules with classification activities and Brandon's Matrix, scoring 34/36. In MIX2, she used CERN examples and question-answer to teach SI and AV, scoring 32/36. Journals highlight challenges with SK (Week 4), addressed by simplifying explanations, and success with SI (Week 5) through relatable examples. Leyla's

practice evolved into a systematic, inquiry-based approach, leveraging RFN visualizations to make NOS holistic, though she noted difficulties with abstract concepts for younger students and limited group activities.

Teacher Melisa initially taught NOS verbally with limited active methods (pre-interview). Post-PD, she gained confidence, integrating NOS through structured plans and inquiry-based activities (post-interview). In MIX1, she taught density using videos and simulations, emphasizing scientific practices (34/36). In MIX2, she used group modelling activities and BRH to teach molecules, scoring 36/36. Journals show challenges with SK (Week 4) due to language barriers, addressed by adjusting materials, and success with SI (Week 5) through CERN discussions. Melisa's practice became more engaging, using diverse methods (e.g., discussions, hands-on tasks), though time constraints and crowded classrooms occasionally limited interactions. She adapted by focusing on problem-solving and structured reflections, enhancing NOS visibility.

Teacher Zeynep initially aimed for a student-centered, inquiry-based approach to teach NOS, focusing on active engagement (pre-interview). Post-PD, she faced challenges balancing NOS with curriculum demands and struggled with SK and M (post-interview). In MIX1, she taught density with simulations and group activities, but classroom management issues limited effectiveness (26/36). In MIX2, she used real-life examples (e.g., jar expansion) and BRH, scoring 30/36. Journals highlight engagement through hands-on tasks (e.g., Week 3 classification), but difficulties with SK (Week 4) and missing M implementation (Week 2). Zeynep's practice fostered scientific curiosity, yet her reflections lacked depth, and time constraints hindered comprehensive NOS integration, requiring more structured curriculum support.

Additionally, teachers are compared and contrasted considering the implementations of NOS-based activities in their classroom practices. Table 4.41 presents a summary of the codes obtained from diverse data sources, which are individual interviews, observation forms, teacher journals, and group discussions.

In the individual interviews, all teachers demonstrated a developing understanding of NOS but varied in confidence and instructional depth. Aylin, Leyla, and Melisa expressed

notable gains in confidence and teaching competence. They believed NOS was teachable and emphasized the importance of structured or systematic instruction. Aylin specifically stated that students enjoyed the lessons and were actively engaged, while Leyla and Melisa highlighted improved strategies and the usefulness of visuals. In contrast, Beren and Deniz felt unprepared and lacking in both content and pedagogical knowledge, despite acknowledging NOS's teachability. They both emphasized the difficulty of AV, M, and SK dimensions, whereas SI and SP were considered easier. Zeynep focused less on pedagogical implementation and more on classroom management issues, although she reported increased confidence and improved strategies. A shared pattern among most teachers was the perception that SI and SP were more accessible, while M and SK were more challenging, requiring more concrete examples or clearer strategies.

The teachers' journals reflected the practical struggles and student responses in the classroom setting. Despite diverse classroom contexts, all teachers experienced challenges in implementation, particularly with time management, materials, and certain NOS concepts. Aylin and Zeynep both struggled with SK distinctions and Brandon's Matrix, and they mentioned difficulties stemming from student age or classroom size. Deniz and Beren faced similar time and resource constraints and had trouble using follow-up questions or aligning assessments with objectives. Leyla encountered difficulty teaching M and SK types but noted that the use of BRH enhanced student motivation. Melisa had mostly positive experiences with student engagement, but also faced technical and time-related difficulties, especially when trying to distinguish SK types. Across the group, student engagement was generally high, but instructional and logistical challenges, particularly regarding SK, M, and assessment, were recurring themes.

Observation data showed how theoretical understanding translated into classroom practice, revealing significant variation in NOS integration and instructional execution. Aylin and Melisa consistently conducted well-managed, student-centered lessons, asked NOS-related questions, covered all objectives, and demonstrated objective reflections. They also used question-and-answer sessions effectively. In contrast, Beren and Deniz showed signs of instructional anxiety and skipped parts of the lesson plans, leading to unclear explanations and less student engagement. Their reflections lacked objectivity, and they struggled to internalize M content. Leyla and Zeynep demonstrated improvement in the

second observation. While Zeynep made strong NOS connections and encouraged student identity as scientists in the first observation, she initially avoided teaching M and conducting group activities. By the second observation, she improved classroom management and successfully conducted group activities. Leyla also improved by managing time better and using visuals and questions effectively. While Aylin and Melisa showed consistent integration, Leyla and Zeynep showed growth over time, and Beren and Deniz continued to struggle with execution.

Group discussions shed light on teachers' overall reflections, preferred strategies, and lingering concerns. Aylin emphasized high student engagement and advocated for more NOS examples and systematic instruction. Teachers Beren and Deniz preferred more teacher-directed approaches, such as simulations and simplified content delivery. They were hesitant about group work and expressed concerns over the lack of NOS-focused resources. Deniz, in particular, mentioned difficulty with NOS assessment and anxiety regarding MoE objectives. Leyla, similarly, noted difficulty with NOS assessment tools and relied on questions and answers for evaluation, while also expressing anxiety about national curriculum limitations. Melisa displayed strong content knowledge, especially in RFN categories, and focused on variables and experiments. However, she acknowledged her students' struggles with SK distinctions. Zeynep showed confidence in group-based science teaching and NOS assessment strategies but intentionally avoided SK due to MoE limitations and expressed concern about addressing non-curricular topics. While Aylin, Melisa, and Zeynep leaned toward student-centered or activity-based practices, Beren and Deniz remained more teacher-directed, and Leyla sat in between, aware of both pedagogical and policy-related challenges.

Table 4.41. The codes obtained from teachers' implementations of NOS-based activities in

Data Sources	Aylin	Beren	Deniz	Leyla	
Individual interview	Students actively engaged and enjoyed scientific thinking Gained confidence in teaching NOS Feels responsible and adequate RFN teachable; SI, AV, SP easier; M, SK harder Needs concrete examples for SK	Still feels inadequate Needs more content and pedagogical knowledge Believes NOS is teachable Emphasizes need for systematic NOS teaching SI, SP easier; AV, M, SK harder	Feels unprepared and lacks confidence Needs more knowledge in science content and pedagogy Emphasizes the importance of systematic instruction Finds SI and SP easier, AV, M, and SK more difficult	Learned to ask NOS-related questions Improved teaching strategies More confident in teaching NOS Highlights visual support Supports systematic NOS integration SI, SP easier; SK, AV, M harder	Gaine throug Devel teachi Believ effecti NOS Suppo NOS i Finds SK, A challe
Teacher journal	Faced personal health and technical issues Needed more time for assessment Struggled with SK misconceptions Found Brandon's Matrix confusing Large class size limited active participation All students were 5th graders	High student interest and engagement Lessons felt meaningful Could not implement SI lesson Minor issues with time and materials Difficulty using follow-up questions for engagement Unable to assess based on objectives	High student engagement and interest Lessons were meaningful Could not carry out SI lesson Faced time and material-related challenges Struggled to use follow-up questions effectively Evaluation didn't align with objectives	Difficulty teaching graphs and M SK types were hard to explain BRH increased student motivation Diverse strategies helped motivation Time management issues in discussion parts	Most exper Faced time- challe Had t mater Diffic distin types Stude active

Table 4.41. The codes obtained from teachers' implementations of NOS-based activities in th

Data Sources	Aylin	Beren	Deniz	Leyla	
Observation forms	**First observation** MIX 1=> AV, SP, SI Students to actively participate in QA She did not refer any NOS issues She asked NOS based questions at the end of the lesson She referred all the objectives Her reflection was objective **Second observation** MIX 2=> AV, M, SP, SI NOS emphasis was appropriate Students to actively participate in QA Evaluated both science and NOS Managed duration effectively Her reflection was objective	**First observation** MIX 1=> SP, SK, SI Did not internalize M Feeling anxious for time management Skipped some parts of the lesson plan Did not explain the questions clearly and engage students Her reflection was not objective **Second observation** MIX 2=> SP, SI Good at time management and evaluation parts Used different teaching materials Skipped some questions Her answers were limited Need to make better explanations	**First observation** MIX 1=> SP, SK, SI Did not internalize M Feeling anxious for time management Skipped some parts of the lesson plan Did not explain the questions clearly and engage students Her reflection was not objective **Second observation** MIX 2=> SP, SI Good at time management and evaluation parts Used different teaching materials Skipped some questions Her answers were limited Need to make better explanations	**First observation** MIX 1=> SP, M Provided more examples Managed time effectively Referred all NOS issues Her students was active through QA Her reflections was objective **Second observation** MIX 2=> AV, SP, SI Taught science and NOS Referred all objectives Used a ppt for visuals and questions Managed time effectively Her students was active through QA Her reflections was objective	**First** MIX Provi examp Mana effect Refer Her st throug Her re object **Secon** MIX Taugh NOS Refer Used and qu Mana effect Her st throug Her re object

Table 4.41. The codes obtained from teachers' implementations of NOS-based activities in th

Data Sources	Aylin	Beren	Deniz	Leyla	
Group discussions	High student engagement Need for more NOS examples Support for systematic NOS instruction	Prefer simulations and Q&A sessions Suggest simplified lesson plans Avoid group work (limited space) Need for more NOS-focused content	Emphasis on teacher-directed notetaking Belief in structured content delivery	Difficulty in NOS assessment tool development Uses Q&A for NOS evaluation Anxiety about MoE objectives	Fami categ Emph varial exper Stude with

4.3. Results of the Third Main Research Question

One of the aims is to evaluate the nature of the online reflective and collaborative professional development program constructed on the RFN framework. The third main research question is “RQ3: How do science teachers reflect on their experiences with collaborative work, as well as learning and teaching of NOS within the context of the PD program structured by the RFN framework?” There are two data sources, which are individual interviews conducted before and after the intervention, and teachers’ weekly journals to evaluate the nature of the program.

For the “individual interview” data source, teachers are asked the questions of “(1) What kinds of teacher training activities do you think are more beneficial? (2) What do you think about teachers’ collaborative work? Do you have any experience with collaborative work with your colleagues? How?” During the pre-interview, after the intervention, they are asked the questions of “(1) You previously mentioned that you took a course on the NOS during your undergraduate years. When you think about that course, how did this PD program contribute to your understanding of the NOS? Did it have any impact? Were there any similarities? “(2) How do you think the PD program on NOS went? What do you think are the strong and weak aspects of the PD program?” “(3) During the NOS training, you did various group work (poster preparation, lesson plan analysis, discussion, lesson plan preparation). What do you think about collaborative work in teacher education?” and “(4) In this PD program, you worked collaboratively with every teacher, either in preparing lesson plans or at least in discussing theoretical knowledge. If you were to evaluate it individually, what would you say? With which participant was it easier to work, and with whom was it more difficult?” and “(5) If this PD program were to be done again, what would you say to "keep it the same and change"? to get information about their experiences with the nature of the PD. The answers to each case are analyzed, and related codes and quotations are reported for each case separately.

For the “teacher journal” data source, teachers answered the questions of “(1) How were your collaborations during this week's workshop (discussing related RFN category, analyzing videos, reviewing lesson plans, or participating in Q&A, etc.)? What do you think about the effectiveness of collaborative activities during this week's workshop (for session

1)?" and "(2) What do you think about your collaboration with your group partner during the lesson plan preparation process? (session 2)" in their weekly journal. Based on seven-week reflections, the effects of the nature workshops on teachers' learning and teaching progress are reported. The answers to each case are analyzed, and related codes and quotations are reported for each case separately.

4.3.1. Case 1 – Aylin's Reflection on the Online Collaborative and Reflective Professional Development Program

Teacher Aylin reflects on her ideas about the online collaborative and reflective nature of the professional development program in both individual interviews and weekly journals. Her reflections on each data source are reported separately with quotations.

Aylin's Interviews

Teacher Aylin, in her pre-interview, asked what kinds of PD programs are beneficial for her and what she thinks about the collaborative work of teachers. The teacher thinks that visual design-related PD activities are the most beneficial. As a visual communication design student, she engages with visuals extensively, making it easier to integrate such elements into their teaching materials. This approach enhances their learning and teaching efficiency, leading them to focus on software and tools related to visual design rather than verbal or theoretical methods. Regarding collaborative development, the teacher has faced challenges due to differences in teaching styles and the traditional content-based approach of colleagues. Being a young educator, she initially struggled to find a cooperative environment, as many teachers preferred conventional methods. Additionally, teachers' workload and fatigue often hinder collaboration. However, the teacher values teamwork, recognizing its importance in handling projects and sharing responsibilities. She presents her ideas as follows:

> "My working style is not something my colleagues are used to because I also do not learn in a conventional way. They tend to be more focused on direct instruction, test performance, and content-based approaches rather than project-based learning. This sometimes creates a disconnect between us, making it difficult to find a collaborative environment. This is also due to the current circumstances—teachers are often too tired. … A collaborative environment is extremely important. There are activities and projects that I cannot manage alone, and even carrying my own materials can be challenging. That is why I need teamwork. …" (Aylin, pre-interview)

After the intervention, she was asked to (Q1) the contribution of the PD program compared to her NOS course taking during her undergraduate years. The teacher noted that while the course involved practical activities, it lacked depth in explanation. The PD program, however, helped them integrate the NOS into their teaching more effectively by encouraging them to ask thought-provoking questions and explore a variety of scientific concepts beyond just experimental aspects. She shares her thoughts in the following way:

> "In the undergraduate NOS course, we focused more on practical applications. Instead of traditional lectures, the professor explained the key concepts in the first week and then moved on. Each week, we were given worksheets—one, for example, was about nuclear energy. The article we received was so neutral that we couldn't fully support or refute it, which led to discussions and questions. Now, I feel more competent in applying these concepts in my lessons. I find myself coming up with questions while teaching and thinking, "If I ask my students this, I can incorporate the NOS into my lesson." Before this training, I rarely had such thoughts, and when I did, they were limited to scientific practices like forming hypotheses or experimental manipulations. Since our professor provided very little detail, I could only add minor elements based on what I remembered. However, now I include more examples from the social aspects of science. I show my students content related to scientific knowledge and discuss scientific methods in greater depth. In short, my teaching has become more diverse and enriched." (Aylin, post interview)

She reflected (Q2) on her ideas about the strengths and weaknesses of the program. She found it engaging and insightful, but personally exhausting due to scheduling conflicts. She suggested starting earlier to reduce fatigue, but acknowledged that the program was overall enriching, allowing for spontaneous recall and application in real classroom settings. (Q3) Discussing collaborative learning, the teacher emphasized the value of working with colleagues, highlighting how teachers often share common struggles but are rarely given structured opportunities to collaborate meaningfully. She found the exchange of diverse ideas, such as learning about experiences from CERN visits or alternative teaching methods like using LEGO instead of modelling clay, to be particularly beneficial.

> "We realized something during this training—you can also see it in the video recordings. As teachers, we often complain about the same things and have common expectations, yet the people in charge of these programs do not facilitate effective collaboration. However, through this training, we understood that when we come together, we can generate amazing ideas and discover completely new perspectives. For this reason, I believe that if this PD program replaced the ineffective training courses provided by the Ministry of Education, it would be much better. We learned so many different ideas and perspectives. For instance, one of us had visited CERN and shared their experience, giving us valuable insights. Another teacher came up with a unique idea that no one else had thought of—like my egg experiment, which no one had tried before. Similarly, when Melisa Teacher mentioned a Lego example, I thought, "Wow, I never considered this! I used to have students use playdough, but now I will switch to Lego." These kinds of experiences are not provided in typical training sessions. They don't give us the time or motivation to collaborate and explore new ideas. That's why I believe this type of collaborative training was incredibly beneficial for us." (Aylin, post-interview)

When assessing individual collaboration (Q4), she found Leyla Teacher to be the most effective partner, as they complemented each other's strengths and weaknesses. Lastly, considering potential improvements for future iterations of the program (Q5), she strongly advocated for maintaining the variety of academic readings but suggested expanding participation beyond science teachers to include educators from other disciplines. She believed that this interdisciplinary approach could enhance discussions and broaden perspectives on the NOS across different fields of study. She put forward her ideas in this manner:

> "The different articles you provided during the lectures were incredibly valuable. I will never forget the one I received—it was an academic article from Koç University about academic manipulation and unethical practices, such as selling academic knowledge for money. But when discussing something as complex as the NOS, I believe such interactive activities are absolutely necessary… One thing I would consider changing is the target group of the program. The NOS should not only be discussed among science teachers. Instead, there should be a mix of social studies teachers, Turkish language teachers, mathematics teachers, and science teachers in the same group. If this program were to be held again, I would definitely want to keep the group activities integrated into the slides. However, the one change I would suggest is expanding the program beyond science teachers, turning it into a broader workshop for middle school educators from different disciplines." (Aylin, post-interview)

Aylin's Journal

Teacher Aylin consistently highlighted the positive impact of collaborative work during the theoretical sessions of the workshops. In week 1, she noted that working with teacher Leyla was highly effective, describing her as a supportive and cooperative partner, although time constraints limited their work. In week 2, she appreciated the exchange of diverse ideas while analyzing lesson plans and deciding on scientific methods, emphasizing how such collaboration could enrich classroom practice. During week 3, she found the group discussions particularly enjoyable and fruitful, with new ideas sparking further debates, which deepened their understanding of scientific practices. In week 4, she described the collaborative activities—like classifying types of scientific knowledge and poster creation—as eye-opening and stated that she planned to apply these ideas across various learning outcomes in her classes. By week 5, she reflected on how discussing different perspectives, especially in relation to the social and institutional dimensions of science, helped reinforce the idea that science should be free from sexist and racist biases. Overall, she found the collaborative elements of each week both thought-provoking and pedagogically valuable. She reflected her thoughts in the following way:

> "It was really nice to hear different ideas being discussed. When we examined the sample activities, we once again realized how much our lesson contributes to the path of science. It was especially valuable to revisit and discuss, from different perspectives, the idea that many sexist and racist attitudes we are familiar with should be kept separate from science. We had a discussion about the example of Salome Gluecksohn-Waelsch." (Aylin, teacher journal, week 5)

Teacher Aylin thinks that they, as a team, demonstrated strong collaboration throughout the planning process. The team divided tasks fairly, ensuring equal contributions and fostering joint decision-making, as seen in week 1. In week 2, she quickly agreed on using a real-life scenario to explain the relationship between distance, speed, and time. Each team member's unique strengths were leveraged, such as Melisa's insights from her CERN visit in week 5, which added depth to the lesson on the SI of science. Leyla contributed creative ideas in week 7 to simplify complex concepts in the case study on elements and compounds. When challenges arose, like in week 7 with time management, they worked together to find solutions. This efficient teamwork, marked by strong communication and mutual support, played a key role in developing effective lesson plans.

4.3.2. Case 2 – Beren's Reflection on the Online Collaborative and Reflective Professional Development Program

Teacher Beren shares her thoughts on the online collaborative and reflective aspects of the PD program through individual interviews and weekly journals. Her reflections on each source of data are presented separately, accompanied by quotations.

Beren's Interviews

Before the intervention, when teacher Beren was asked about the most beneficial types of PD activities for her, she emphasized the importance of trainings that raise awareness, especially those focusing on inclusivity, such as how to involve students with special needs in lessons. She recalled an ÖBA-based training on this topic that she found particularly meaningful. Although she cannot always implement every new teaching method, she expressed a strong interest in learning about them. Methods like flipped learning and inquiry-based strategies (e.g., predict, observe, apply) were mentioned as examples of approaches she enjoys learning through professional seminars. Regarding the format and structure of PD activities, she clearly stated her preference for interactive workshops over

passive learning environments. She finds seminars most effective when participants are actively involved, writing, doing, and participating alongside the instructor. She is not interested in simply sitting through presentations or watching videos; she wants to be engaged and hands-on during the learning process, which is why she prefers workshop-style training. In terms of collaborative practices among teachers, the teacher shared her contrasting experiences. After graduation, she worked at a private institution for six months, where collaboration was minimal. Most teachers there were inexperienced, and everyone worked individually without much communication or cooperation. However, in her current school, she experiences more collaboration within her subject team. She and her colleagues, who teach 5th grade, often share ideas about lesson content and materials. They exchange teaching notes, suggest useful videos for classroom use, and maintain open communication about their methods. However, she noted that they don't co-create lesson plans or engage in formal collaborative planning. Instead, their collaboration is informal and based on regular interaction and mutual support. Still, she finds this form of cooperation quite valuable for professional growth. She presents her ideas as follows:

> "I prefer interactive training sessions. I enjoy the ones where we are active, along with the presenter, where they make us write something, do something—more like workshop-style activities. Otherwise, I don't enjoy just sitting in a conference hall and listening or just watching a video on a screen. I need to be active there and learn in an active way…. I worked at a private institution for the first six months after I graduated. And most of the teachers were inexperienced, so we didn't really work as a team or in collaboration. But at my current school, I work with my subject group… I share with them, like, "I'm at this topic, and I taught it this way. How did you teach it?" Or I might say, "I designed this material," or I've used materials they designed because I really liked them … But we don't prepare a common lesson plan or anything like that. It's more like when we meet and talk, we exchange ideas, share videos, and so on." (Beren, pre-interview)

After the intervention, teacher Beren was asked four questions about the nature of the program. Regarding the teacher's previous undergraduate course on the NOS (Q1), she reflected that the course had limited impact on her understanding. In fact, she believes it contributed negatively to her conception of scientific knowledge. During her undergraduate years, she recalls learning inaccurate ideas such as the misconception that theories evolve into laws over time. Interestingly, the recent PD program helped her to retroactively realize what the NOS course was intended to teach. She stated that she didn't learn much about the AV and SI aspects of science during her undergraduate studies. In contrast, the PD program clarified these dimensions for her, helping her grasp the NOS more accurately and meaningfully.

> "I don't think the course I took was sufficient. In fact, I feel like I learned some misconceptions during that undergraduate course on the NOS. E.g., I only became aware of the concept of "model" in science through this recent PD program. Before that, I had learned that in a completely wrong way at my university. I had this idea in my head that "theories turn into laws,". So that course didn't really have a positive impact on me. … It didn't touch on things like the AV of science, or its SI aspects. I didn't get to explore those in that course. The instructor tried a different method to engage us, but it wasn't very effective. So overall, this PD program really helped me better understand the NOS." (Beren, post-interview)

Evaluating the PD program as a whole (Q2), the teacher found it quite beneficial, especially in enhancing her theoretical understanding and classroom application. She expressed appreciation for the clarity and professionalism of the presentations and felt that the facilitator's subject expertise made complex ideas more accessible. One challenge she noted was related to timing; the evening sessions were sometimes tiring after a full day of work, and the lesson plan preparation required considerable effort. However, she didn't see any content-related weaknesses in the program. She now finds herself recalling NOS concepts while planning lessons and has realized that integrating these concepts into regular science topics is easier than she initially thought. Importantly, the program helped her expand her own content knowledge, which was one of her primary goals.

> "The theoretical sessions weren't too long—they didn't really go beyond the planned two hours. But preparing the lesson plans was a bit tiring for me, since I'd usually come home in the evening and have to work on them then. So, timing was the only downside for me. Content-wise, I didn't find any weaknesses at all, honestly. The presentations and your explanations were all strengths, in my opinion. Even if the topic is abstract, your professional expertise made everything much clearer and easier to understand and follow. So I'd say that was a strong point. Professionally, it was very beneficial because every time I filled out a lesson notebook, I'd think about the learning outcomes related to the NOS. I'd start wondering, "What could I include here? What approach would work for this topic?" And I realized that integrating the NOS into lesson plans isn't actually difficult. And most importantly, I improved my own knowledge. That was my main goal from the start." (Beren, post-interview)

Concerning collaborative group work during the program (Q3), the teacher had a nuanced perspective. While she enjoyed activities such as poster preparation, article analysis, and group discussions, she felt that the lesson plan critique component could have been more effective. She observed that most teachers, including herself, were hesitant to provide critical feedback, often offering only superficial comments. She attributes this partly to time constraints and partly to discomfort with giving direct critiques. She also noticed that dominant personalities often led the planning, sometimes limiting her ability to contribute meaningfully. Despite these challenges, she acknowledged that the collaborative elements, especially in smaller groups, were generally productive and enjoyable. However, she

emphasized that the personalities and teaching styles of group members played a major role in determining the success of collaboration.

> "I thought we could have been more active during the lesson plan critique sessions. We focused more on creating the lesson plans than critiquing them. And since those sessions often came at the end, some teachers hesitated to comment or only gave surface-level feedback. So while everything else about the collaborative work was great, I think we held back when it came to critiquing each other's lesson plans. But other activities—like the poster preparation, article discussions, news analysis, and video commentary—were all really engaging. I found them all helpful and effective. In lesson planning, every teacher has their own style and way of delivering a lesson, and they want that to be reflected in the plan. I personally found that a bit challenging—not technically, but mentally. Even when I expressed my ideas, I often received critical or skeptical responses. It made me feel a bit disheartened. On the other hand, when I worked with someone more collaborative, that really motivated me." (Beren, post-interview)

When asked to reflect on individual collaboration experiences (Q4), she pointed out that her experiences varied significantly depending on the partner. She highlighted Zeynep as both the easiest and most difficult person to work with. Zeynep's strong experience and confidence often led to high-quality lesson plans, but this dominance also left little room for her to contribute her own ideas or adapt the plans to her teaching context. On the other hand, she greatly appreciated working with Melisa, whom she described as open to discussion and capable of building on shared ideas, leading to more balanced and motivating collaboration. She also mentioned working briefly with Leyla and Aylin teachers. With Leyla, she felt the plans were somewhat superficial and lacked depth, while her limited collaboration with Aylin was still positive but too brief to form a strong impression.

> "Actually, the answer is the same person. The easiest and the hardest to work with was Zeynep teacher. She had a lot of prior experience with lesson planning—it really showed. As soon as we picked a topic, she'd say, "Oh, I already have a lesson plan for that," and she'd start outlining how she teaches it. But when I'd say, "I don't have access to lab materials," or "I can't find these resources," she'd just reply with suggestions like, "You can do this or that instead." So it was easy in the sense that she took full charge. But at the same time, it was hard because I couldn't contribute my own ideas based on my students' needs and my context. The most enjoyable collaboration for me was with Melisa. I think we created some great lesson plans together. She was someone who could take an idea and build on it collaboratively. I also worked with Leyla once. That was fine too, though we didn't go into much depth; our lesson plans were pretty basic and based on very straightforward ideas. I also worked once with Aylin. As for Deniz, we never had the chance to collaborate on lesson plans at all. So, overall, Melisa was the most enjoyable to work with, Zeynep was both the easiest and hardest." (Beren, post-interview)

When asked for suggestions about improving the program (Q5), she emphasized that while she was satisfied overall, a few structural elements could be reconsidered. For instance, she suggested that the sequence of NOS categories might be reorganized, though she acknowledged that the existing order was also logical. She felt that some components, like AV and SP, could be elaborated more. Additionally, the participant proposed modifying

the lesson plan presentation process. Instead of each teacher explaining their own plan in detail after peer review, they recommended focusing discussions on unclear points or specific feedback to avoid redundancy and save time. In her view, brief clarifications or responses to specific questions would suffice. Despite these minor suggestions, she felt the timing, content, and group activities were all well-balanced and effective overall.

> "…Perhaps SP could be more comprehensive, as I think about the SI aspects of science. But when we talk about SP, it's usually just experiments, observations, and predictions. Maybe it could be more detailed. The values in the AV section again… I'm not sure, maybe it could be more comprehensive. Otherwise, I'm very happy with the explanations and everything; the training I received was quite sufficient. As I said, these things could change. In the lesson planning session, we all prepare lesson plans. Then, everyone reviews each other's lesson plans. I don't think we need to explain our own lesson plans again after reviewing each other's. I feel like it's a waste of time, because I've already read the lesson plan and reviewed its steps. Also, in group work during the theoretical lessons, the time allotted was actually sufficient, so I don't have an issue with that. After preparing the lesson plans, in the feedback sessions, I think the part where the teacher explains the lesson plan could be removed." (Beren, post-interview)

Beren's Journal

Teacher Beren reflected on her experiences about the collaboration during the theoretical session of the workshops. In the first week of the workshop, her collaboration with teacher Aylin was quite productive. They discussed meritocracy while reviewing articles and exchanged ideas about our lesson plans. The collaborative activities, especially examining an example lesson, were surprisingly efficient and productive, which was a pleasant surprise. In the second week, however, collaboration seemed less effective as many teachers were sick. During group discussions, she noticed that other teachers also shared the same misunderstandings, making collaboration more difficult. In the third week, her collaboration with Leyla was more productive. They watched a video together and discussed scientific practices, teaching strategies, and the teacher-student relationship. However, she felt that as the weeks went by, collaborative efforts were declining, with teachers being less willing to provide feedback on lesson plans and questions. The fourth week showed an improvement in collaboration due to some conceptual contradictions among her colleagues, which increased participation. As they became more comfortable with each other, it was easier to express their thoughts. During the poster activity, she worked with Melisa and Deniz. They discussed and made decisions together about the layout, photo selection, and color. However, she must mention that Deniz was not as active in the process. In the fifth week, they discussed an article about unethical academic practices, which led to a productive

exchange of ideas. They also briefly analyzed a news article about the social and institutional aspects of science, but the discussion was less engaging as each group only presented their own article. Overall, the article discussions were helpful, but the news article discussion did not generate much interaction. However, she found that week's theoretical lessons to be engaging and fluid.

Teacher Beren thinks that collaboration between teachers helps them create good lesson plans. According to her, working in similar types of schools helps teachers to determine the structure of the lesson plan. For example, Teacher Beren loved to collaborate with Teacher Leyla and Melisa because they work in public schools like Teacher Aylin. The physical conditions of their schools, the number of students, and the students' profiles are similar. On the other hand, she struggles to work with teacher Zeynep because she wants to adapt her school activities to the lesson plans, and reaching a consensus can be problematic to some extent. For example, Beren reflects her ideas for the collaboration with Teacher Leyla as:

> "We prepared the lesson plan with my colleague, Leyla. Since the student levels in our classes and our school environments are similar, it was easy to create a common lesson plan. First, we outlined the possible aspects of the lesson plan, then we combined the parts we liked from each other's ideas to create a unified plan. While I was searching for visuals online, my colleague was writing the planned lesson. I believe our collaboration, communication, and relationship were harmonious. Her being cooperative and valuing my opinions made working with her in a group project much easier." (Beren, teacher journal, week 3)

4.3.3. Case 3 – Deniz's Reflection on the Online Collaborative and Reflective Professional Development Program

Teacher Deniz reflected her views on the online collaborative and reflective elements of the PD program in both individual interviews and weekly journals. Her reflections from each data source are presented separately, with relevant quotes included.

Deniz's Interviews

Teacher Deniz, in her pre-interview, explained that she strongly values practical, face-to-face PD activities that include individualized feedback and observation. She emphasized the importance of communication skills, suggesting that teachers should receive

in-person diction and classroom presence training. According to her, such training should not be conducted in large groups or online, as she believes effective development requires a "third eye" someone who can observe, provide feedback, and help teachers recognize habits they may not be aware of. She also suggested that assignments such as recording oneself while teaching could be beneficial for self-reflection. Moreover, she highlighted the need for support in classroom management and communication strategies tailored to different student age groups, especially adolescents. She stressed that pedagogical training should include real-life classroom dynamics and offer strategies for building student engagement. Regarding collaboration, the teacher reported limited experience due to her background in private institutions, where individual work is more common. However, she described positive experiences collaborating with subject groups, particularly during the preparation for common exams. She expressed that such cooperation enhanced her sense of belonging and motivation, and that collaboration led to the emergence of richer ideas. Nonetheless, she pointed out that collaboration among teachers is not widespread and often only occurs at the beginning and end of the academic year, unless required by institutional needs such as standardized exams. Overall, she supports collaborative work and believes it should be a more integral part of school culture. She articulates her thoughts in this manner:

> “I haven't had much experience, you know, in schools and such. Here's how I see collaboration: e.g., with my subject group… When we brainstorm about a topic with my group, I think the participation of the group brings a certain enthusiasm to the work… Collaborative power is a good thing. Different ideas are born from unity. Those ideas enrich our thinking. That’s why I care about unity…. At the beginning of the year, there's a "what are we going to do" meeting, and at the end of the year, another meeting. But actually, there’s nothing like: “How do you teach? How are we progressing? What are we going to do next in science?” … This year it happened a little, but that was because of the joint exams.” (Deniz, pre-interview)

After the intervention, teacher Deniz is asked how this PD program contributed to her understanding of the NOS, compared to the course she took in her university years. She reflected on a previous undergraduate course about the NOS but felt that the topic had been addressed only superficially at that time. According to teacher Deniz, the PD program offered a much more meaningful and practical understanding of the NOS. Unlike the earlier theoretical exposure, the recent experience allowed for hands-on engagement, which facilitated deeper learning. The participant emphasized the formation of conceptual frameworks during the two-month program, such as distinguishing between scientific knowledge, scientific practices, and the socio-theoretical aspects of science. In contrast, the university-level course lacked depth and failed to leave a lasting impact. Thus, the participant

found this recent program significantly more beneficial and transformative in terms of their understanding. She states her ideas as follows:

> "I remember taking a course related to the NOS during my undergraduate studies, yes, but I don't recall my instructors emphasizing it very much. I mean, it wasn't really integrated into me. I think it was covered quite superficially. I feel that I grasped the concept much better during these two months, more so through practice and experience in the field. E.g., I didn't have any frameworks in mind before; everything was scattered. Now, I've started forming mental frameworks like: "this belongs here, this is scientific knowledge, this is scientific practice, these are the social and theoretical aspects of science." So, I don't think what I received at university was sufficient. I can say that I understood things better in the field and during this two-month process." (Deniz, post-interview)

The participant had a generally positive perception of the PD program. Collaboration with peers, particularly with Leyla and Aylin, teachers, was described as enjoyable and efficient. The participant appreciated the synergy with teacher Leyla, noting a shared teaching approach and aligned thinking, which facilitated smooth planning. Similarly, working with Aylin was marked by quick decision-making and effective teamwork. However, collaboration with Melisa proved to be more challenging due to a mismatch in communication and ideas, which led to hesitation and difficulty in progressing. Despite these individual differences, the participant valued the experience overall and found the group work to be one of the program's strengths.

Looking ahead, the participant suggested some improvements for future implementations of the program. One key recommendation was to form groups based on grade level or subject similarity to ensure more coherent and efficient planning among participants. Additionally, grouping teachers who work at similar paces could help avoid disruptions and make the process smoother. The participant also pointed out the occasional interruptions due to illness or other personal reasons and proposed having a substitute or backup teacher system in place to maintain continuity. Overall, the participant expressed satisfaction with the structure and outcomes of the program, noting only a few logistical issues that could be refined.

> "What should stay the same? I think the way it progressed was nice, but when forming the groups, it would be better if they were composed of teachers handling the same grade levels or covering similar topics. Especially if the groups were selected among teachers who are, like, "Which grades do you teach?" "This one and that one," then we could mix and match different teachers accordingly. Grouping teachers who go at a similar pace might also help. That way, there wouldn't be any interruptions or difficulties in the program. Other than that, I think it went quite well overall. It's just that sometimes weekly disruptions happen—we can get sick or miss a session for different reasons…. But overall, I was satisfied with it in general. These were the only shortcomings I noticed." (Deniz, post-interview)

Deniz's Journal

Teacher Deniz reflected on her experiences with the collaborative activities during the theoretical knowledge-based sessions of the workshops. Based on her weekly journal responses, it is clear that the workshops provided meaningful opportunities for professional growth, particularly through collaborative activities. Throughout the five weeks, the teacher emphasized how group discussions, whether centered on article evaluations, video analyses, or lesson plan reviews, helped identify personal gaps in knowledge and offered different perspectives that enriched understanding. In the first week, she realized that science is not about reaching absolute truths but getting closer to them and reflected on the ethical responsibilities of scientists. By exchanging ideas, the group was able to reach common conclusions, highlighting the value of diverse viewpoints. In subsequent weeks, the teacher appreciated how collaborative tasks revealed and corrected misconceptions, supported mutual learning, and enhanced lesson planning by integrating shared knowledge. Video analyses, though sometimes challenging to interpret alone, became more meaningful when discussed as a group. The teacher consistently noted how working with others fostered critical thinking and creativity, especially in activities like creating educational posters or analyzing scientific news articles. Overall, the journal entries reflect a strong appreciation for collaborative learning. The teacher repeatedly acknowledged the benefits of different teaching styles, mutual support, and critical feedback, all of which contributed to a deeper understanding of the NOS and improved instructional strategies. She reflected her experiences about the collaborative work through the workshop as:

> "In this week's workshop, we watched a video about scientific types of knowledge and discussed it. It was a video that explained the concepts clearly with examples, helping us gain clarity. Interpreting it as a group also diversified our ideas. Then, we did a group activity on scientific knowledge types and classified them. The discussions I had with my group partner made it easier for me to distinguish between different types of knowledge." (Deniz, teacher journal, week 4)

Teacher Deniz consistently reflected positively on the collaborative process of lesson plan development with her group partners throughout the seven weeks. From the beginning, there is a clear appreciation for the partner's strengths, often described as more experienced, quick-thinking, and meticulous. In many entries, the teacher acknowledges their partner's significant contributions, such as taking the lead in preparing activities, finding relevant materials, and helping to fill in any gaps. Despite this, the partnership was not one-sided; there was a strong sense of mutual support, where both individuals shared ideas, inspired

each other, and worked toward common goals. As the weeks progressed, the collaboration appeared to have evolved into a balanced and synergistic relationship. Words like "enjoyable," "harmonious," and "complementary" were frequently used, indicating a high level of engagement and satisfaction. Even in situations where challenges arose, such as struggling to come up with ideas, the teacher highlighted how open communication and mutual respect helped overcome obstacles and eventually led to a successful plan. Overall, the reflections suggest that working with a dedicated and supportive partner not only made the planning process more effective but also enriched the teacher's own development and confidence.

4.3.4. Case 4 – Leyla's Reflection on the Online Collaborative and Reflective Professional Development Program

Through individual interviews and weekly journals, Teacher Leyla offers insights into the online collaborative and reflective nature of the PD program. The reflections from each data source are provided separately, along with direct quotations.

Leyla's Interviews

Teacher Leyla was asked which kind of PD programs are beneficial for her in her pre-interview. She expressed dissatisfaction with the current PD programs, noting that they are often impersonal and ineffective. According to her, many seminars and training programs they attended during their early career lacked meaningful interaction and were not tailored to specific needs or subjects. She thought that a more intimate and engaging setting, with less emphasis on information overload, would be more beneficial. She also highlighted the lack of support in their specific field and the challenge of finding meaningful PD opportunities. Additionally, she mentioned that, despite her own willingness to learn and improve, she often finds herself working alone, with her efforts not being recognized or supported by colleagues. This lack of shared PD and subject-specific training results in a fragmented and less effective teaching environment. She states her ideas as follows:

> "When I attended events as a trainee teacher, they were always held in conference rooms where someone was presenting, and everyone was interested in different things, with no communication. It needs to be in smaller environments, and there shouldn't be too much information overload. I mean, opening a slide, reading it, moving on, reading it, moving on – that shouldn't be the way. I think about it now, and during my time as a trainee, I attended many seminars. If you ask me what I learned from them, I can honestly say nothing, nothing stuck with me. They were mostly general sessions meant for all teachers. Besides that, I don't receive any support based on my subject…. There is no meeting point on the same level as the other teachers. Since we don't receive the same training, or let me say, since we don't receive training based on our subjects, it's not very effective." (Leyla, pre-interview)

Teacher Deniz also reflected on their experiences with collaborative work. She discussed the challenges of collaborative work among colleagues, especially within larger teams. She described a situation where, despite being part of a group of teachers, one senior teacher bears most of the responsibility, with others not participating as expected. She also mentioned that some senior teachers, due to previous experiences of their efforts going unrecognized, have become disengaged and no longer wish to collaborate. This highlights the difficulties teachers face when there is a lack of mutual support and accountability in their workplace, further exacerbating the challenges of creating a collaborative, effective teaching environment.

Teacher Leyla has not taken any NOS courses during her undergraduate studies, but some courses she took referred to some categories of RFN. She was asked how she found the PD program in terms of learning NOS after the intervention. She reflects that she had previously heard of the FRA but hadn't explored it deeply. After participating in the PD program, she feels that her understanding of this approach has become much clearer. Initially, she only remembered general concepts, such as the openness of scientific knowledge to change, but now she feels more confident in integrating the approach into lesson plans and analyzing the scientific nature of different aspects. She believes that this PD program was beneficial for her. She appreciated the opportunity to work with other teachers and the fact that the plans they created considered different classroom environments. She also highlighted that the program didn't only focus on the NOS but also incorporated national curriculum standards, which made the plans more comprehensive. Teacher Leyla mentioned that she now feels capable of integrating the NOS into any topic, which she didn't think was possible before. However, she would have liked to have analyzed more well-designed lesson plans, which could have been more instructive.

The teacher emphasized the importance of collaborative work in teacher training. She explained that they typically don't prepare lesson plans on their own, as their plans are based on their own teaching experience. However, the collaborative approach allowed teachers to create more realistic and adaptable lesson plans. The teacher finds this experience valuable, especially in terms of saving time and benefiting from the strengths of other colleagues. She also mentioned that working with others opened her eyes to new methods she hadn't considered before, which was an enriching experience.

Teacher Leyla shared that she had varied experiences working with different colleagues. They described how each teacher had unique strengths, such as critical thinking, content knowledge, or creativity in lesson planning. For example, she enjoyed working with Deniz Teacher because of her collaborative nature, and she appreciated Zeynep's ability to create meaningful connections in lessons. The teacher also mentioned that working with Aylin was beneficial because of their shared focus on presentation and visual content. The overall experience was positive, with no significant difficulties reported in collaborating with others.

Finally, the teacher was asked for her suggestions about the PD program for future trainings. The teacher believed the content of the program should remain the same, particularly the structure, which starts with introducing a topic, followed by lesson planning, and then the reflection on the implementation. However, she suggested that if there were no time constraints, the program could be spread over a longer period, allowing for more in-depth reflection and less rushed planning. Additionally, she proposes that all materials, plans, and resources could be gathered in a folder for easy access and reference, which could enhance the experience.

Leyla's Journal

Teacher Leyla reflected on her experiences for the collaborative activities during the theoretical parts of the workshops each week. Based on her journal answers, it is evident that collaborative learning played a significant role in enhancing both the effectiveness and depth of the workshops. From the very first week, she highlighted how group discussions such as article evaluations, lesson plan reviews, and explorations of the aims and values of science

provided opportunities to gain new perspectives and justify one's ideas with logical evidence. Each week presented a different theme, yet the consistent reflection emphasizes that collaboration led to a richer understanding of the content and improved the quality of the outcomes. In weeks where the teacher felt less confident, such as during discussions on scientific methods, working with peers allowed for mutual support, idea exchange, and critical thinking. Group work not only increased motivation but also led to the creation of higher-quality materials. The analysis of scientific practices and video reflections revealed common misconceptions, which were clarified through group discussions. These moments demonstrated the value of collaborative clarification and peer learning. The teacher also noted that in topics such as the classification of scientific knowledge and the socio-institutional dimensions of science, working together made complex information more approachable. Poster activities, brainstorming sessions, and article discussions allowed for the merging of various viewpoints, resulting in more comprehensive understandings. Even in time-constrained tasks like finding relevant news articles, collaboration helped manage the workload more efficiently and encouraged reflective evaluation of the information presented. She expresses her thoughts for the collaboration work in the SI workshop in this way:

> "… We were deeply affected by the article we read about copyright. We critically analyzed every detail in the article and realized how difficult the process is for scientific works to be accepted by institutions. Working as a group in reviews, activities, and discussions allows us to approach the topic from different perspectives, providing a broader approach. Discussing the articles related to the topic is both enjoyable and productive. Each of us shares the existing knowledge we have and draws attention to what we learned from the article. Recognizing the main themes in the article, resolving existing confusion with the explanations provided, and conveying the article completely to other colleagues is made easier through group work." (Leyla, teacher journal, week 5)

Over the course of seven weeks, Teacher Leyla reflected on her collaborative experience while preparing lesson plans with a group partner. In the first week, she highlighted the challenge of integrating the NOS into the lesson plans but emphasized that their collaboration allowed them to create a detailed and effective plan, with both offering critical feedback that led to a more coherent final product. By the second week, she noticed the value of considering the dynamics of two different classrooms, which helped them develop a versatile plan. They moved away from traditional approaches, like presenting atomic history after teaching atomic models, and instead designed an activity where students would create models based on historical contexts. This flexibility and open dialogue with their partner allowed for a more thoughtful and dynamic lesson. By the third week, she

appreciated how working collaboratively allowed them to consider different student profiles, making the plan more comprehensive and adaptable. The input from her partner's professional expertise also contributed to her personal growth. In week four, she praised how they worked together to align the lesson content with scientific standards, ensuring it was appropriate for a range of students. The partnership allowed them to create a plan more efficiently than if they had worked alone. In week five, teacher Leyla reflected on how collaborative efforts helped them develop a more concise and fluid lesson plan, which would have taken much longer to complete on their own. The group work led to a more balanced and effective plan, adaptable to various classrooms. By the sixth week, she appreciated how working together sped up the process and allowed for continuous evaluation and refinement of the plan. In the final week, the teacher noted that both partners shared similar sensitivities toward the lesson's content and used brainstorming and storytelling techniques to enhance engagement, paying close attention to details like visuals and text presentation. In general, the teacher found that collaboration enriched the planning process, providing opportunities for feedback, diverse perspectives, and efficient lesson development.

4.3.5. Case 5 – Melisa's Reflection on the Online Collaborative and Reflective Professional Development Program

In both individual interviews and weekly journals, Teacher Melisa expresses her thoughts on the online collaborative and reflective features of the professional development program. Each reflection is reported individually, with quotations provided for clarity.

Melisa's Interviews

Before the intervention, teacher Melisa was asked what kinds of PD programs are beneficial. Teacher Melisa emphasized the importance of having a knowledgeable and prepared trainer. She pointed out that even when a training is rich in content, it lacks effectiveness if there is no opportunity to practice what is being learned or engage with the trainer in meaningful ways. The teacher highlighted her positive experience with a design thinking course offered by the Ministry of Education, where the presence of skilled trainers and hands-on practice contributed to a highly valuable learning experience. In contrast, she critiqued online platforms and courses with limited interaction or practical application,

noting that these often result in minimal retention and application of the material. She puts forward her ideas in this manner:

> "…. the instructor could be very good, but if the process is not well-prepared, it remains incomplete. Or, if the content is great but there's no chance to apply it, it's still not good. We just listen and move on. If I were to go on ÖBA now, I've probably watched about 30-40 videos this semester. But how much of it stuck with me, how much of it can I apply? Maybe 2% or 5%. Therefore, I want the opportunity to apply what I learn, I want an instructor who supports and guides me in that, and I want to really trust my instructor." (Melisa, pre-interview)

When it comes to collaborative work, teacher Melisa expressed frustration with the lack of opportunities for teamwork at their school. She described an environment where collaboration is not encouraged, and teachers often work in isolation. Despite a desire to collaborate, especially with colleagues from different subjects, she noted that they have rarely had the chance to engage in collaborative projects due to logistical constraints and a lack of openness from other teachers. This response underscores the challenges of fostering a collaborative teaching culture, highlighting the need for a more supportive and open environment in schools. It can be said that the teacher's reflections suggest that while she values interactive and hands-on professional development, she had limited success with collaboration due to institutional barriers. She presented her ideas about collaboration in schools as follows:

> "Unfortunately, no. Our school is not very open to this. Generally, we are in a school with the mindset of "Don't create extra work for us, don't show anyone that you are doing something different." Therefore, whatever I do, I try to do it on my own. I only have one math teacher friend, and unfortunately, we never get to teach the same classes together. So, I don't have a colleague from a different subject with whom I can collaborate. In fact, most of the time, even when I ask other science teachers at school, "Should we do this like this?", they just say, "Okay, you do it." So, I don't have much experience with collaboration. Honestly, I don't think teachers are very open to it, or I just haven't encountered anyone who is." (Melisa, pre-interview)

Teacher Melisa is another teacher who is familiar with some components of RFN before participating in the PD program. She was asked about her experiences with the PD program considering her previous experiences. Teacher Melisa shared her prior knowledge of the FRA, stating that they were somewhat familiar with it before the program. However, she highlighted the benefit of the PD program in helping them clarify previously vague concepts. She emphasized that the program's structured approach allowed her to understand scientific methods and models more clearly and confidently. She acknowledged that while she initially had a general understanding, the program helped solidify her knowledge through practice and feedback, making her more certain about the concepts she had learned.

Teacher Melisa reflected on her positive experience with the PD program, noting that it was both enjoyable and informative. She appreciated the collaborative work structure, where small group discussions and exchanges of ideas helped enhance her learning. Despite some challenges with scheduling and coordinating with peers, she recognized that the program's structure and content, such as reviewing lesson plans and studying relevant materials like videos and articles, were very beneficial. She particularly valued the hands-on approach and how the content was delivered, allowing her to engage with real-life applications of theoretical knowledge.

Also, she believed that the collaborative nature of the program was highly effective. She highlighted the importance of working in smaller groups, where everyone contributed to the product. She found that in larger groups, some individuals tend to be passive, but in this case, everyone actively participated. This dynamic fostered a productive and creative environment where diverse perspectives were shared. She also appreciated the practical aspects of group work, such as creating posters or analyzing videos together, which allowed them to benefit from different viewpoints and ideas. She expressed her experiences about the collaborative activities during the PD program in this way:

> "We weren't a very large group in this study. We were in pairs, like in small groups of two or three people. You know, it was mandatory to produce a final product. In larger groups, it's easier to stand aside and stay quiet. In most of the face-to-face collaborative activities I've participated in—what we'd call collaborative work—there's usually at least one quiet person in the group, just like with students. But in this particular study, I think 100% of the participants performed; everyone contributed something. In that sense, it was definitely very effective. Sometimes we watched the videos together, other times we watched them separately and then discussed them, and each time, everyone shared a different perspective. So, everyone was able to express a unique point of view. Even when we were making the poster, which is usually something one person ends up doing, there was still a strong sense of collaboration. In that respect, I think we truly experienced a great example of collaborative learning." (Melisa, post-interview)

When asked about Melisa's individual experiences with different colleagues, she found it challenging but rewarding to work with various teachers. She particularly appreciated working with Deniz teacher who lacked prior knowledge of the subject, as their fresh perspective prompted teacher Melisa to reconsider her approach. However, she also noted that certain lesson plans required more time to refine, as she felt some needed adjustments after initial preparation. She found the collaborative nature of the program

invaluable, as it fostered an environment where everyone was open to feedback and suggestions.

If the program were to be repeated, teacher Melisa would suggest keeping the overall structure intact but recommends more time for the lesson plan development stage. She believed that while the collaborative and theoretical aspects of the program were well-structured, there should be more flexibility in the time allotted for lesson planning and reflection. She proposed breaking down the lesson planning into smaller, more manageable parts or adapting the format to include additional time for review and refinement. Despite these suggestions, she overall found the program to be well-organized and beneficial. She acknowledged that scheduling conflicts and the unique needs of different schools made some parts of the program more challenging, but she was still pleased with the overall program.

> " I think the structure is great. The way it starts with a theoretical presentation and discussion, and then, when appropriate, immediately moves into group activities for practice—that's really well-designed. Later on, developing a lesson plan was a bit challenging in terms of time. Maybe that part could be broken down into smaller sections or restructured somehow. It could be adapted to a Zoom-style format, where there's an initial introduction, then participants split into groups and work independently for a while, and then come back together for a wrap-up session. … the videos we watched were excellent, the articles were great, and reviewing lesson plans was definitely a valuable experience. And we reviewed each other's lesson plans and gave feedback on them. Overall, I found the flow of the whole program very successful. The only part that I found difficult and might benefit from a change is the lesson plan implementation segment. Doing all that in a single evening, even when it stretched beyond the two scheduled hours, was really demanding. I found myself wanting to go back and revisit it." (Melisa, post-interview)

Melisa's Journal

Teacher Melisa, in her weekly journals, reflected on her ideas about collaborative activities during the theoretical part of the workshops. Considering her 5-week reflections, it can be said that a consistently positive experience with collaborative group work and the structure of the workshops. In the first week, analyzing articles on the AV of science allowed for a deeper understanding of abstract concepts through concrete examples, while working with different groups enriched the learning experience by offering varied perspectives. Although lesson planning was time-consuming, it served as a valuable guide for future practice. In the second week, discussions about the Brandon's matrix use sparked confusion in a productive way, highlighting opportunities for deeper learning. Collaboration through small and large group discussions supported comprehensive understanding and

synchronized teamwork via online documents, enhancing productivity. Week three further emphasized the benefits of shared perspectives, with video analyses inspiring self-reflection and peer contributions enriching the conversation. The fourth week provided clarity on scientific knowledge types through video analysis and example-based discussions, while collaborative poster work was both efficient and creatively satisfying. Finally, in week five, teacher Melisa appreciated the opportunity to work on diverse examples in small groups and then share insights in larger discussions. As a result, the teacher found the collaborative activities for Session 1 of the workshops engaging, well-structured, and conducive to meaningful learning.

Throughout the seven weeks of lesson plan preparation, teacher Melisa reported a positive and collaborative working relationship with her group partners. She highlighted mutual respect, effective communication, and a balanced division of labor as key elements contributing to her productivity. In the early weeks, she emphasized her effort to share ideas without being overbearing, particularly given her prior experience with the NOS. As the process progressed, she noted that differences in perspectives were addressed through open dialogue, and decisions were made collaboratively. Tools like online document editing were frequently mentioned as valuable in facilitating synchronous collaboration. While one week brought up a slight mismatch between the collaboratively produced plan and the teacher's personal classroom needs, this was viewed as a learning opportunity rather than a failure in teamwork. In the final week, the teacher especially appreciated her partner's thoughtful questions and constructive feedback, which helped refine the lesson plan design. It can be said that Melisa's reflections suggest a growing appreciation for the collaborative process and its impact on both personal and professional development. She states her ideas as follows:

> "I worked smoothly with my group partner, but the resulting plan wasn't something I could directly use in my lesson. After the session, I changed the introduction part and the section related to the experiment setup in the lesson flow. Personally, I tend to open up gradually in any kind of work. I felt that, during the preparation of this plan, my communication with my group partner didn't really give me the opportunity to open up." (Melisa, teacher journal, week 6)

4.3.6. Case 6 – Zeynep's Reflection on the Online Collaborative and Reflective Professional Development Program

Teacher Zeynep reflects on her ideas about the online collaborative and reflective nature of the PD program in both individual interviews and weekly journals. Her reflections on each data source are reported separately with quotations.

Zeynep's Interviews

During her pre-interview, Teacher Zeynep stated that the most beneficial PD activities for her were those that integrated both subject knowledge and pedagogical training. She enjoys workshops that help her learn more about science and new technologies like robotics. However, she needs to translate this knowledge into classroom practice due to gaps in her pedagogical background. She thinks learning about child and adolescent psychology is very important because students today are different from those in the past, and teachers need to understand them better. She prefers workshops where she can take part in activities instead of just listening. Being active helps her learn more. For her, professional development should be useful, practical, and focused on both teaching and understanding students.

Teacher Zeynep views collaboration among colleagues as highly influential but believes its effectiveness depends on the mindset and motivation of the individuals involved. She talked about working with teachers of different ages and styles; some of them used old methods, and this made it harder to move forward. For her, ideal collaboration involves partners who are open to challenges, eager to improve, and willing to go the extra mile in planning and experimenting. She values colleagues who are curious, research-driven, and proactive, citing her previous department head as an inspiring example. According to her, a collaborator's attitude is often more crucial than their academic expertise. She finds it difficult to grow professionally when working with someone reluctant to put in extra effort. Constructive collaboration, in her view, involves pushing boundaries together rather than settling for what's easiest. She conveyed her experiences about the collaborative work in the following way:

> "In previous years, I have worked with many different subject groups. …. When I look at group work or think about collaborative work … it's really valuable if my team member likes challenges. I always fear that a team member who says, "Let's not bother, teacher" will dull me. … So, when we approach collaboration, the character of the person we are working with is just as important as their academic qualifications. … E.g., if we are planning a lesson and say, "Let's do this experiment here, let's do this activity," it's much more valuable to work with someone who says, "No, let's add this too," or "Let's research more, let's find a new experiment". These kinds of people are very valuable to me." (Zeynep, pre-interview)

Teacher Zeynep was asked for her reflection on the online reflective collaborative PD program. She believes that the PD program significantly contributed to her growth, especially in comparison to their undergraduate courses. She felt that the program was more comprehensive, particularly after the changes in the national curriculum. The teacher highlighted that the program made her feel as though they were learning the material for the first time, despite having previously studied the NOS during their undergraduate years.

Teacher Zeynep mentioned that the strong point of the program was the development of a comprehensive pool of lesson plans that were regularly reviewed, allowing for a deeper understanding and engagement with the materials. However, a key challenge was working in groups, as some colleagues had difficulty collaborating due to differences in class size, resources, and facilities, such as laboratory equipment. This made it challenging to find common ground in the group work.

> "The strong point... We created a wide pool of lesson plans, and since we did this regularly every week, we participated in the lessons with a better grasp of the lesson plans for that week. It also helped me be more active in my school life, in my lessons. The weak point was this: We worked in groups every week, and naturally, things with groups were different. For example, my colleague Beren has a larger class, and she can have difficulties with group work, or her lab isn't suitable, making it hard to do lab work. It was very difficult to find common ground in these situations. I can say this was a weak point. Other than that, it was an active, productive, and great experience for me." (Zeynep, post-interview)

Considering the collaborative activities, teacher Zeynep strongly favors group work during the PD program, as it allows them to be more active. She admitted to struggling with passive listening and expressed that being in a group where they could participate actively made the learning experience more effective for them. Group work allowed her to stay engaged and benefit more from the training. She shared that working with Melisa was particularly easy because of Melisa's creativity, positivity, and willingness to explore challenging lesson plans. In contrast, she found it harder to collaborate with other teachers, like Beren and Aylin, due to a perceived lack of enthusiasm or effort to push the boundaries

of lesson planning. She noted that the limitations in available resources or the personal circumstances of their colleagues may have contributed to these difficulties.

When asked what could be improved if the program were to be applied again, Teacher Zeynep suggested adjustments to the session timings, as late finishes were exhausting. While she appreciated the content of the program, she felt that presentation materials could be shared beforehand to help those who struggle with passive listening. In general, she was satisfied with the program's structure but suggested a few changes to better fit individual learning styles. She states her suggestions as follows:

> "The hours should be changed, but I know that this was decided collectively. The timing was really exhausting for me. The fact that it ended late was tiring. However, in terms of content, I don't think anything should change. I think it can continue as it is. I would prefer this more, but I am speaking for myself. Since I am not a good listener, I find it difficult to listen, so presentations could be shared in advance. The active part you present could be shorter, and we could have worked on it. I am saying this for myself because I find it easier to study on my own rather than listening to someone. In fact, most people are not like me. So, I can't really say anything about that. I think it can stay the same." (Zeynep, post-interview)

Zeynep's Journal

Throughout the five-week workshop series, teacher Zeynep found collaborative activities to be highly beneficial for both personal development and group interaction. In the first week, she expressed that group discussions, such as article evaluations and lesson plan reviews, were the most engaging, noting that they were more productive in smaller group tasks. While group question-and-answer sessions were less participative for her, the collaboration within the group was still valuable. The teacher felt that the exchange of ideas within the team was particularly fruitful, especially for developing ideas and fostering a positive dynamic. In the second week, the group discussions were very effective due to the variety of responses from participants, showcasing the diverse perspectives and knowledge within the group. This made the discussions particularly insightful and allowed the teacher to gain new viewpoints. Collaborative activities were also productive as she worked well with a colleague to develop an effective lesson plan. By the third week, the teacher found that discussions on scientific practices and the video analysis were particularly impactful. Initially unsure of the content, after analyzing the video as a group, the teacher's understanding evolved. She appreciated the high dynamic of the group, which helped in generating productive and meaningful collaboration. In the fourth week, the teacher

observed that when all group members contributed their thoughts and ideas, the discussion became more meaningful and enriching. Collaborative activities, particularly those involving the classification of scientific knowledge and the poster activity, were seen as highly valuable, as they allowed for active participation and the exchange of ideas that matched the teacher's preferred learning style. Finally, in the fifth week, the teacher found the group discussions to be very effective, especially when listening to peers' experiences. The review of articles and news related to the social and institutional aspects of science was particularly compelling, as the discussions brought attention to crucial and striking points. Teacher Zeynep expressed her experiences about the SP workshop as:

> "The video analysis, especially after initially watching it, significantly influenced my thoughts once we analyzed it within the group. The group dynamics were very productive in this regard. I believe we formed a great group in this training. It was a high-energy group where everyone effectively shared their different knowledge. The activities were very productive because they were influenced by this dynamic." (Zeynep, teacher journal, week 3)

Throughout the seven-week process of preparing lesson plans, teacher Zeynep experienced both highly collaborative and productive partnerships with different group members. In the first week, the teacher noted some differences in class compatibility between herself and her group partner but made efforts to develop a plan that addressed these differences. She felt the outcome was successful. In the second week, despite facing some challenges with time management, she felt that the exchange of ideas and division of labor made the collaboration worthwhile and efficient. By the third week, the teacher described the collaboration as "fantastic," appreciating the shared knowledge and creativity with her partner. She expressed gratitude toward her colleague, Melisa, for contributing to a strong, imaginative work. In the fourth week, the collaboration continued to be positive, with the teacher highlighting the good dynamic within the group and how quickly and enjoyably the lesson plan was developed. In the fifth week, the teacher again felt that the collaboration was successful, noting that the exchange of ideas resulted in a well-thought-out plan. Week six was marked by a highly enjoyable and productive partnership, with the teacher emphasizing the efficiency and value of their teamwork. However, by the seventh week, although she acknowledged the great collaboration, she faced difficulty aligning with certain activities. She noted challenges in agreeing on common activities for the lesson, but despite this, she felt that the group's overall teamwork remained strong.

It can be said that teacher Zeynep's reflections on the collaborative process demonstrate a consistent pattern of positive teamwork, with a focus on idea exchange, effective division of labor, and mutual respect. However, she also highlighted occasional challenges when trying to find common ground on specific activities, which is a natural part of any collaborative process.

4.3.7. Summary of the Reflection on the Online Collaborative and Reflective Professional Development Program of Cases

Teacher Aylin reflected on the online collaborative and reflective PD program through interviews and journals. In her pre-interview, she highlighted the effectiveness of visual design-focused PD activities, leveraging her background in visual communication design to enhance teaching materials, though she faced challenges in collaboration due to differing teaching styles and colleagues' traditional approaches. Post-intervention, Aylin noted the PD program enriched her NOS understanding beyond her undergraduate course, enabling her to integrate diverse scientific concepts into lessons through thought-provoking questions. She valued collaborative group work for exchanging innovative ideas (e.g., using LEGO instead of playdough), though scheduling conflicts caused exhaustion; she suggested interdisciplinary participation and maintaining academic readings. Her journals emphasized productive collaborations, particularly with Leyla, where diverse perspectives and shared tasks (e.g., using real-life scenarios) enhanced lesson planning, despite time constraints.

Teacher Beren shared her experiences in the PD program through interviews and journals. In her pre-interview, she favored interactive, workshop-style PD activities over passive seminars, appreciating inclusivity-focused trainings (e.g., ÖBA courses), and described limited collaboration in her early career but more informal idea-sharing in her current school. Post-intervention, Beren found the PD program corrected her undergraduate NOS misconceptions (e.g., theories turning into laws), clarifying aspects like AV and SI, though evening sessions were tiring. She valued collaborative activities but noted hesitancy in lesson plan critiques due to time constraints and dominant group members, finding Melisa the most collaborative partner. Her journals highlighted productive early collaborations (e.g., with Aylin on meritocracy discussions) but noted declining engagement over weeks, with

article discussions on unethical practices being insightful despite less interactive news analyses.

Teacher Deniz reflected on the PD program via interviews and journals. In her pre-interview, she prioritized practical, face-to-face PD with individualized feedback, valuing communication and classroom management training, and noted limited collaboration in private schools but positive experiences during joint exam preparations. Post-intervention, she found the PD program more impactful than her superficial undergraduate NOS course, forming clearer conceptual frameworks (e.g., scientific practices, socio-theoretical aspects). She enjoyed collaborating with Leyla and Aylin but faced challenges with Melisa due to communication mismatches, suggesting grade-level-based grouping and backup systems for absences. Her journals emphasized how group discussions (e.g., on ethics, scientific knowledge) corrected misconceptions, enhanced lesson planning, and fostered critical thinking, despite occasional passivity in larger group activities like news article discussions.

Teacher Leyla provided insights into the PD program through interviews and journals. In her pre-interview, she criticized impersonal PD seminars, preferring smaller, interactive settings, and described challenges in collaboration due to disengaged senior colleagues and a lack of subject-specific support. Post-intervention, Leyla appreciated the PD program's clarity in deepening her NOS understanding (e.g., FRA concepts), finding collaborative lesson planning more realistic and timesaving, though she desired more well-designed lesson plan examples. She valued working with Deniz and Aylin for their collaborative and creative strengths, suggesting a longer program duration and resource consolidation for future iterations. Her journals highlighted how group discussions (e.g., on copyright, scientific practices) broadened perspectives, improved lesson plans through diverse inputs, and made complex topics more approachable, enhancing her instructional strategies.

Teacher Melisa reflected on the PD program through interviews and journals. In her pre-interview, she emphasized the need for knowledgeable trainers and practical application in PD, critiquing non-interactive online courses like ÖBA, and noted limited collaboration opportunities at her school due to an unsupportive culture. Post-intervention, she found the PD program clarified her prior FRA knowledge, enhancing her understanding of scientific

methods through structured practice, and appreciated small-group collaboration (e.g., poster creation, video analysis) despite scheduling challenges, suggesting more time for lesson planning. She valued Deniz's fresh perspective but noted adjustments in lesson plans for personal use. Her journals underscored productive small-group discussions (e.g., on Brandon matrix, scientific knowledge types), balanced collaboration with partners, and mutual respect, though she occasionally struggled to open up during planning.

Teacher Zeynep shared her reflections on the PD program via interviews and journals. In her pre-interview, she valued PD integrating subject knowledge (e.g., robotics) and pedagogy, emphasizing active workshops and understanding student psychology, and preferred collaborative partners who are challenge-driven and proactive, finding less motivated colleagues hindering growth. Post-intervention, she found the PD program more comprehensive than her undergraduate NOS studies, appreciating the extensive lesson plan pool but noting challenges in group work due to resource disparities (e.g., lab access), and enjoyed collaborating with Melisa for her creativity while struggling with Beren and Aylin's perceived lack of effort; she suggested adjusting session timings and pre-sharing materials. Her journals highlighted productive group dynamics (e.g., video analyses, scientific knowledge classification), with collaboration enhancing lesson plans despite occasional disagreements on activities, reflecting overall positive teamwork and professional growth.

Moreover, six teachers are compared and contrasted considering the experiences of participating in the collaborative and reflective PD programs. Table 4.42 presents a summary of the codes obtained from two data sources, which are individual interviews and teacher journals.

During the pre-interview phase, all six teachers expressed dissatisfaction or limitations with prior PD experiences, but their specific concerns varied. Aylin, Beren, and Leyla criticized current PD opportunities for being either impractical or dissatisfying. Aylin cited workload and fatigue as barriers and expressed a preference for traditional methods. Similarly, Beren believed PD was too focused on materials and lacked practical application, while Leyla voiced dissatisfaction with existing formats altogether. In contrast, Deniz, Melisa, and Zeynep favored practical and subject-integrated PD. Deniz preferred face-to-face formats over large or online sessions, and Zeynep emphasized constructive

collaboration and a need for PD that blends pedagogy with content. Melisa, like Deniz, criticized online PD for lacking interaction and practical value. Regarding collaborative experiences, most teachers had either limited or negative encounters. Beren and Leyla experienced superficial collaboration, mostly focused on materials, with no co-planning or deeper involvement. Aylin also faced collaboration challenges, mainly due to differing teaching styles. Deniz reported no prior collaborative experience, while Melisa stated there were no opportunities for teamwork. Zeynep stood out slightly by emphasizing the importance of constructive collaboration, although she did not describe having experienced it directly.

Post-interview data reflected a more nuanced and generally positive shift in teachers' perceptions following the PD program. All six teachers acknowledged gaps in their pre-NOS training, with Aylin, Beren, Deniz, and Zeynep specifically describing their undergraduate NOS education as superficial and sometimes misleading. Leyla and Melisa had pre-existing knowledge but still lacked application-based experience. In terms of the PD program itself, reactions were generally favorable but mixed. Deniz and Melisa highlighted the program's practical, hands-on components and creativity, while Aylin and Leyla pointed out scheduling and time constraints. Beren reflected that the program improved her theoretical understanding, though she still faced time-related challenges. Zeynep described it as more comprehensive than past trainings. Collaborative work was more positively received post-PD, though challenges remained. All teachers noted improvement, but the depth varied. Deniz, Leyla, and Melisa described effective collaboration, where they benefited from colleagues' strengths, developed flexible lesson plans, or gained new perspectives. Zeynep contributed to a shared lesson pool, marking a notable shift from her earlier emphasis on collaboration without much evidence of participation. Aylin and Beren still reported some difficulties. Aylin noted common challenges but also learned from peers, while Beren enjoyed certain activities (e.g., posters) but highlighted that dominant voices often shaped planning. For suggestions going forward, Aylin and Beren advocated for diverse materials and more inclusive planning. Leyla and Melisa emphasized the need for more reflection time and better coordination, while Zeynep recommended adjusting session timing and pre-sharing materials to enhance productivity. Deniz was the only one who did not suggest specific improvements, indicating general satisfaction with the collaborative experience.

The reflections from the six teachers show both shared and varied experiences about collaborative and reflective work during the theoretical and lesson planning sessions of the PD program. In the first session, all teachers appreciated the collaborative environment, highlighting the exchange of diverse ideas and the benefits of group discussions. For instance, Aylin and Beren found discussions clarified theoretical concepts like the RFN components, while Deniz emphasized mutual learning and enhanced critical thinking. Teachers Leyla and Melisa reflected improved understanding and motivation through group discussions and concrete examples. Zeynep highlighted the value of new perspectives and how key points were effectively communicated. Overall, all participants recognized the effectiveness of collaboration in deepening their understanding and planning to implement the ideas in their teaching.

In the second session, during the collaborative lesson plan development, teachers again reported positive yet uniquely nuanced experiences. Aylin focused on joint decision-making and problem-solving, while Beren discussed the impact of school context and some challenges in content alignment. Deniz valued the strengths and support of her partner in the planning process. Leyla emphasized student-centered planning and her own professional growth. Melisa noted effective teamwork, communication, and the practical use of tools like Google Drive. Zeynep's reflections pointed to efficient time and task management and enjoyable planning. Despite different contexts and group dynamics, all teachers reported enhanced collaboration, practical skill development, and improved planning capacity.

Table 4.42. The codes obtained from teachers' reflections on the collaborative and re

Data Sources	Aylin	Beren	Deniz	Leyla	
Pre-interview	**PD preferences** Workload and fatigue hinder PD engagement Preference for traditional methods **Experience on collaborative works** Challenges due to different teaching styles	**PD preferences** PD limited to materials, not practical application **Experience on collaborative works** Collaboration exists but only on content/materials No co-planning or deeper collaboration	**PD preferences** Prefers practical PD Prefers face-to-face over online or large group formats **Experience on collaborative works** No prior collaboration experience	**PD preferences** Dissatisfied with current PD programs **Experience on collaborative works** Collaborative work is challenging Senior teachers resist collaboration	**PD p** Critic for la and p **Expe** **colla** No o teamv collal
Post-interview	**Pre-NOS experience** Undergraduate NOS course was superficial **PD Program:** Scheduling conflict **Collaborative Work:** Shared common challenges Learned from others' experiences **Keep:** Diverse readings **Improve:** Include non-science teachers	**Pre-NOS experience** Undergraduate NOS course superficial, caused misconceptions **PD Program:** Improved theoretical understanding Faced time-related challenges Enjoyed hands-on activities **Collaborative Work:** Liked posters, articles, Dominant voices led planning **Keep:** AV & SP components **Improve:** More focused feedback, avoid repetition	**Pre-NOS experience** Undergraduate NOS course depth **PD Program:** Gained practical and meaningful understanding **Collaborative Work:** Overall good collaboration Faced difficulties communicating with Melisa **Keep:** Program structure & outcomes **Improve:** —	**Pre-NOS experience** Heard of FRA, no deep understanding **PD Program:** Felt more confident in applying the approach Analyzed well-designed lesson plans **Collaborative Work:** Helped develop realistic and flexible plans Benefited from colleagues' strengths **Keep:** Content as is **Improve:** More time for reflection, less rushed planning	**Pre-N** Pre-k FRA. **PD P** Enjoy infor Faced coord Produ creati **Colla** Bene persp Pract **Keep** devel **Impr** addre sched speci

Table 4.42. The codes obtained from teachers' reflections on the collaborative and reflec

Data Sources	Aylin	Beren	Deniz	Leyla	
Teacher Journal for Reflection on session 1	**Collaboration Experience:** Exchanged diverse ideas Enjoyed and benefited from group discussions Discussions clarified the RFN category **Effectiveness:** Planned to apply ideas in various learning outcomes Found discussions fruitful for understanding	**Collaboration Experience:** Reviewed articles and exchanged ideas Communication improved as group comfort increased **Effectiveness:** Helped grasp RFN components Exposed and corrected misconceptions	**Collaboration Experience:** Identified personal knowledge gaps Gained alternative perspectives **Effectiveness:** Corrected misconceptions Supported mutual learning Boosted critical thinking and creativity Deepened NOS understanding and teaching strategies	**Collaboration Experience:** Enriched workshop content Gained new insights through discussions **Effectiveness:** Improved content understanding Increased motivation Higher-quality materials created Helped manage workload Encouraged reflection	**Colla** **Expe** Unde ideas exam Poste effici creati **Effec** Activ engag struct Prom learni
Teacher Journal for Reflection on session 2	**Collaboration experience for LP development** Fair task division Joint decision-making Strong communication and support Solved time issues together	**Collaboration experience for LP development** Improved lesson planning School context influenced planning Conflict with partner over school-specific content	**Collaboration experience for LP development** Partner's strengths were helpful Shared ideas and goals Gained confidence and development	**Collaboration experience for LP development** Created detailed and adaptable plans Considered diverse student needs Personal and professional growth Improved visuals and structure	**Colla** **exper** **devel** Respo balan Open resolv Effec tools

5. DISCUSSIONS

In the following section, the findings were discussed based on the three main research questions.

5.1. Science Teachers' Perception of the Nature of Science

In order to determine the change in science teachers' perception about the nature of science after participating in the professional development program structured by the RFN framework, teachers were asked to conduct visual representations and individual interviews. The findings of both data sources for each RFN category were summarized and discussed in the literature below.

When considering all RFN categories, it can be said that the online collaborative and reflective PD program structured by the RFN framework enhanced science teachers' perception of NOS. Their visualizations became more sophisticated and holistic. Prior to the intervention, many teachers demonstrated a limited or naïve grasp of several RFN categories. For instance, some teachers viewed scientific methods as rigid, linear procedures. However, after the intervention, teachers used Brandon's matrix and offered examples that reflect the variety of scientific methods. These results are consistent with earlier studies on pre-service science teachers. Kaya *et al.* (2019) conducted a 14-week teacher education intervention to develop pre-service science teachers' perception of RFN. They used the RFN questionnaire and interviews before and after the intervention. They found a significant difference in general and for all RFN categories, not including scientific practices. In the current study, science teachers were more familiar with scientific practices compared to other categories, and a general development was found for all RFN categories. Demirel, Sungur, and Çakıroğlu (2023) conducted a qualitative survey study to investigate science teachers' views about NOS and their integration of NOS in their lessons through semi-structured interviews. The general results showed similarities that teachers used scientific practices and methods interchangeably, and teachers were aware of the social institutions aspects of science. Azninda *et al.* (2021) aimed to determine in-service science and non-science teachers' perceptions about NOS based on the RFN framework. They found that both teacher groups

had a good level of understanding of the aims and values of science, and even they got high scores from the questionnaire for the social-institutional aspects of science, their explanations were limited considering political power structures.

The results of the visual representations showed that teachers generally have a naïve understanding of the aims and values of science before the intervention. Most of them focused on social aims and values, such as serving humanity, solving problems, and developing society; only two of them referred to epistemic aims and values, such as objectivity, validity, ethics, etc. However, after the intervention, their codes varied (see Table 4.1) and they referred more to epistemic cognitive and social aims and values such as novelty, decentralizing power, honesty, accuracy, critical examination, addressing anomalies and counter instances, objectivity, etc. Because these concepts were so abstract, teachers had difficulty in visualizing some of them. In this regard, individual interviews provided detailed information about teachers' perceptions. It was found that, compared to the visual representations, teachers generally mentioned more codes about the aims and values of science in their pre-interview. They made the connection between the development of scientific knowledge, some scientific practices, and methods. However, after the intervention, the number of codes (see Table 4.2) increased, and they generally referred to more aims and values compared to the visual representation data source. In the context of aims and values, the results are similar to Kaya *et al.* (2019) that preservice teachers mentioned serving humanity, understanding the universe, and ethical issues as aims and values before the intervention, while after the intervention they referred epistemic, cognitive and social aims and values science such as serving to humanity, prejudice and bias, honesty in science, accuracy of scientific knowledge, and scientific literacy. Demirel *et al.* (2023) have found similar results that teachers had a limited understanding of epistemic-cognitive aims and values, primarily emphasizing the practical benefits of science. Most teachers concentrated on the social aims of science. These findings are consistent with Aksöz's (2019) study, in which she conducted interviews with 12 science teachers with different science branches to determine their perceptions about aims and values and social-institutional aspects of science. She reported that the obtained codes are mainly about social aspects, which are serving to humanity, understanding the universe, increasing science literacy, and ethics. Kurt and Kaya (2024) in their study investigated teachers' views on NOS based on the RFN framework. For the aims and values category of RFN, they found that

teachers mainly mentioned the codes of serving humanity, understanding the universe, explaining events, explaining Earth, solving problems and searching truth which are generally social aims and values.

For the scientific methods category of RFN, both visual representation and individual interview data sources have consistent findings that teachers had a very naïve understanding of scientific methods before the intervention. They perceived scientific methods as research methods and a step-by-step process including asking a question, constructing a hypothesis, testing the hypothesis through experiments, analyzing data, and reporting results. If the hypotheses are not supported, then it continues to reconstruct hypotheses. Some teachers perceived scientific methods as practices and mentioned data collection, inductive and deductive reasoning. After the intervention, their perception developed. They became aware of the diversity of scientific methods, referred to the Brandon's Matrix to explain diverse scientific method approaches, which are manipulation with hypothesis testing, and not hypothesis testing methods, and non-manipulation with hypothesis testing and not hypothesis testing methods (see Table 4.2). Through the discussions and examples from the history of science teachers were aware of their misconceptions about scientific methods. However, in some cases, it became hard to internalize diverse scientific methods. For example, teacher Deniz and Zeynep had difficulty in visualizing different scientific methods and provided specific examples in their interviews. Likewise, Kaya *et al.* (2019) found that pre-service teachers perceived scientific methods as a step-by-step method before the intervention. After the intervention, their perception developed, and they mentioned diverse methods used in science, including manipulation and non-manipulation, and forming hypotheses or not. The results are parallel to Demirel *et al.*'s (2023) study, which found that pre-service teachers generally perceived scientific methods as universal scientific methods with some steps, such as stating the problem, forming a hypothesis, testing through experiments, and reporting. The studies conducted with teachers based on the Consensus View have also similar results that teachers perceived scientific methods as a linear process (Abd-El-Khalick and BouJaoude, 1997; Aslan and Tasar, 2013). The main justification for this approach is the belief that students require a simplified and cognitively less challenging depiction of scientific methods (Erduran and Dagher, 2014). Irez (2009) suggests that this may be due to how scientific methods are portrayed in textbooks and the curriculum. In another study, Ioannidou and Erduran (2021) examined how teachers understand scientific

methods, specifically the diversity of scientific methods. The results of the empirical study revealed that most teachers demonstrated an adequate understanding of the fundamental components of Brandon's Matrix. Nevertheless, over half of the participants exhibited a naïve view of scientific methods that they perceive consider manipulation and hypothesis testing as essential elements of scientific investigations. The results are parallel to the study conducted by Kartal and her colleagues (2018), who developed a continuing PD program for teachers to investigate the change in teachers' NOS perception based on the Consensus View. They concluded that regarding the tenet of the scientific method, 72% of the teachers had a naïve understanding before the intervention, whereas after the intervention, 66% demonstrated an informed understanding. After the intervention, there was a significant rise in the proportion of teachers recognizing that the scientific method is neither a fixed, step-by-step process nor a singular, universal approach.

The results of the visual representations and individual interviews for the scientific practices category of RFN indicated that teachers generally had more prior knowledge about scientific practices compared to other categories. Even some teachers made the connection to the scientific methods, they mentioned experimentation and observation as the fundamental scientific practices before participating in the PD program. After the intervention, their visuals were similar to the Benzene Ring Heuristics; they referred to almost every component of BRH, which are prediction, real world, explanation, modelling, scientific activities (experimentation, observation, classification), and data. On the other hand, it was noticed that teachers generally did not refer to social scientific practices, which are discourse, reasoning, and social certification, in both data sources (see Tables 4.1 and 4.2). It may be because they focused mainly on six practices in the benzene model. However, they generally feel more familiar with the scientific practices category, too. In the context of scientific practices, results show similarities with Kaya *et al.* (2019) that in pre- and post-interviews, teachers mentioned diverse scientific practices such as experiments, observations, and data; however, after the intervention, pre-service teachers elaborated their perceptions about scientific practices, and they referred to BRH to explain scientific practices. Demirel *et al.* (2023) in their study found that teachers used the concepts of scientific practices and methods interchangeably, which indicates that teachers did not have an informed understanding of scientific practices. It was reported that teachers mostly stated experimentation and observation as scientific practices, which is parallel to the current study.

In contrast to the findings of this study, Kurt and Kaya (2024) found that most of the teachers have very limited understanding of scientific practices. They mentioned the codes of practical science, science making, pedagogical activities, making predictions, observation, experimentation, doing research, asking questions, and data collection. Erduran and Kaya (2018) in their study used BRH as a teaching tool for an empirical project for pre-service teachers. They used visual representation before and after the intervention. They found that the pattern for the representation of scientific practices was so complex that seven pre-service teachers showed a large difference, three a medium difference, three a small difference, and one no difference.

The findings of visual representations and individual interviews for the scientific knowledge category of RFN indicated that teachers had prior knowledge about the characteristics in nature, such as tentative nature, based on empirical evidence, cumulative development of scientific knowledge, proven, supported knowledge, etc. However, only two teachers mentioned types of scientific knowledge as theories and laws (see Tables 4.1 and 4.2). This may be due to their undergraduate course experiences, as most NOS courses are designed based on the Consensus View. Also, it was noticed that the teacher generally did not distinguish the functions of diverse scientific knowledge before the intervention. Even two teachers had the misconception that theories become laws when supported by enough experiments. After the intervention, they visualized different types of scientific knowledge through the TLM table, which had been shown to them during the PD program. It was found that only teacher Deniz held this misconception in her post-visual, but in her post-interview, she did not refer to it. The results were consistent with the study conducted by Kaya *et al.* (2019) that pre-service teachers referred to the tentativeness of scientific knowledge, the accuracy of scientific knowledge, and supported and tested knowledge in their pre-interview. After the intervention, they referred to different types of scientific knowledge and the growth of scientific knowledge. The results are in line with the studies that teachers have a naïve understanding of the diversity of scientific knowledge (Demirel *et al.* 2023; Kurt and Kaya, 2024). They found that teachers hold misconceptions about the functions of theories and laws when they are asked explicitly about their relationships. These findings are consistent with previous research conducted with teachers, showing that the majority possess a naïve understanding of the relationship between theories and laws (Guerra-Ramos, 2012; Aslan and Tasar, 2013; Mihladiz and Doğan, 2014; Wahbeh and Abd-El-Khalick, 2014). For

example, in Mihladiz and Doğan's (2014) the teachers' responses indicated that they tend to believe laws are certain and universal, representing the finalized forms of theories, whereas theories are viewed as flexible and subject to modification. Moreover, Erduran and Kaya (2018) in their study found that all 14 pre-service teachers' pre- and post-drawings showed a big difference that after the intervention, teachers emphasized the key issues about different knowledge types and the growth of scientific knowledge.

Finally, the change in science teachers' perception about social-institutional aspects of science was investigated. The findings of visual representation and individual interview data sources indicated that teachers' perceptions developed; they provided more codes after the intervention (see Tables 4.1 and 4.2). They started to think holistically about the effects of diverse aspects together. Before the intervention, the teacher mainly made connections to social values, social certification, dissemination of science, and social organizations and interactions. After the intervention, they referred scientific ethos, social values, political power structures (the effects of governments, gender inequality), professional activities (examining other studies and writing conference proposals), social certification and dissemination (sharing scientific knowledge with others, reliability of the study), financial systems and social organization and interactions (e.g. NASA, TÜBİTAK, research institutions, institute of science in universities). It was found that teachers internalized this category more easily than others, making connections to real life, history of science, technology, and familiar scientific organizations. In the context of social-institutional aspects of science, Kaya *et al.* (2019) found similar findings that after the intervention, pre-service teachers' perception developed and they mentioned many subcategories of SI, such as political power structures, professional activities, scientific ethos, scientific institutions, and financial systems. Aksöz (2019) and Kurt and Kaya (2024) calculated the frequencies for each sub-category of the SI separately in their descriptive studies. Aksöz (2019) found that when teachers asked questions separately for each sub-category of SI, they made a connection to science and gave reasonable examples. Teachers generally have a limited understanding of the social certification and dissemination sub-categories of SI. The results are similar to Kurt and Kaya's study (2024), which found that science teachers made sensible, appropriate, and sufficient comments for SI aspects. In their study, some teachers could not distinguish between social values and scientific ethos; on the other hand, the codes obtained for social certification and dissemination were well grounded. The results are

parallel with the study conducted by Okan (2021), which found that teachers had a good understanding of the social-institutional aspects of science, which she explained as a result of the fact that SI is closely connected to everyday life. Azninda and Sunarti (2021) in their study focused on science and non-science teachers, and they conducted the RFN Questionnaire and interviews. Their findings support the current study that although teachers scored highly in the SI category from the questionnaire, they struggled to offer clear explanations and relevant examples, particularly regarding political dimensions in the interview.

It was found that science teachers' suggestions for the educational applications of NOS developed after the intervention. Before the intervention, science teachers generally suggested using hands-on activities, conducting experiments, using technology, asking questions about NOS, encouraging curiosity, mentioning scientific institutions, referring to the history of science, and including NOS in the science curriculum. However, they did not specify how specifically they can teach diverse aspects of NOS. The results are parallel with the study conducted by Kurt and Kaya (2024) they in which they asked in-service teachers for suggestions for teaching NOS. They suggested that the integration of the NOS into the Turkish science curriculum by emphasizing categories like M and SK, suggesting that students could better internalize science through examples of how scientific knowledge is developed. They recommended including specific NOS examples, such as lesson strategies and activities, inspired by international curricula like Japan's, to provide practical guidance for teachers Additionally, teachers suggested reducing curriculum content to allow more time for research and scientific activities like observation and explicitly embedding NOS as a distinct topic or objective to ensure its essential role in the curriculum. However, they did not provide specific suggestions for teaching NOS categories.

In the current study, after the intervention, teachers' suggestions developed, they provided more specific teaching strategies for teaching diverse categories of RFN such as using visuals, using FRA Wheel, introducing Brondon's matrix, explaining TLM table, directing questions about the diversity of scientific methods, different types of scientific knowledge, social values, and scientific ethos, providing cases from the history of science, visiting scientific institutions such as universities, research centers, TUA, TÜBİTAK etc., group discussions, enabling students to get experience about scientific projects, sharing news

about science, making posters, discussing how reliability and validity in scientific studies was done, using simulation, showing videos, watching documentaries, invitation of scientists to the school etc. These results are consistent with the earlier studies on pre-service science teachers that NOS intervention developed pre-service teachers' specific pedagogical approaches (Cullinane and Erduran, 2022; Kaya *et al.*, 2019).

5.2. Science Teachers' Translation of NOS Understanding into Their Instructional Practices

In the current study, teachers' translation of NOS understanding into lesson planning was examined through individual interviews, teacher journals, lesson plans, and group discussions during the second session of the PD program. Additionally, teachers' translation of teaching practices was examined through individual interviews, teacher journals, observation forms, and group discussion during the third session of the PD program. The results of the two sub-research questions provided information about how six teachers translate their NOS understanding into their instructional practices.

The teachers' NOS understanding, shaped by the PD program, significantly influenced their lesson planning, though the integration process revealed both strengths and challenges. A key finding was their strong reliance on the example lesson plans provided during the PD, which they frequently mirrored in their own plans. They benefited from example lesson plans that included RFN objectives, activities, visuals, discussion questions, and assessment tools while developing their own lesson plans. They generally adapted them or used the same tools, for example, in the example lesson plan, BRH was used for the evaluation part of the lesson. Two cases use BRH in the evaluation part of their lesson plans. This aligns with Aksöz *et al.*'s (2023) study, in which the authors suggested that teachers should heavily use the materials they were provided; thus, materials, including NOS, should be developed.

A significant challenge was the tendency to treat NOS as a separate entity rather than embedding it throughout the lesson. In several plans, NOS was addressed only in specific sections, often the assessment phase (e.g., in lessons on friction force or phase changes), rather than being woven into the lesson's core activities. The researcher's feedback during

reflection sessions highlighted this issue, prompting discussions that encouraged a more holistic approach, though some teachers continued to struggle. This reflects Erduran and Dagher's (2014) FRA framework, which notes that teachers often isolate NOS often as an add-on due to unfamiliarity with its epistemic dimensions. Similarly, Leden *et al.* (2015) found that teachers often compartmentalize NOS due to a lack of pedagogical content knowledge (PCK), though the current study's teachers showed improvement over time with structured PD support.

Another challenge came up when trying to match weekly RFN categories with required science topics, since the topics didn't always fit well with certain NOS aspects. For instance, integrating scientific knowledge into a lesson on phase changes was challenging for teachers, as the topic was better suited to scientific practices, leading to forced or superficial integration in some cases. In the current study, while the teachers struggled due to their limited experience with NOS, it helped them gain valuable experience and pushed them to think more creatively, trying different ways to fit NOS into their lessons and coming up with new ideas to make it work. Kaya *et al.* (2019) found that their study highlighted that longer programs enable teachers to better integrate NOS ideas. In order to overcome this problem, two subsequent weeks only including lesson plans and reflection sessions were organized to improve teachers' ability to align RFN categories with various topics.

Teachers reflected that collaborative lesson planning was highly beneficial for them. It allowed them to leverage diverse school contexts, teaching methods, and activity ideas, enhancing the adaptability of their plans. For example, teachers from schools with varying physical conditions (e.g., limited access to labs) shared strategies to overcome these constraints, such as using simulations instead of hands-on experiments. Additionally, this collaboration made them feel more comfortable and confident in their planning process, as they could rely on shared expertise and support rather than working in isolation. It also enabled them to learn diverse teaching approaches, such as integrating role-playing or storytelling to teach NOS concepts, broadening their instructional repertoire. Vescio *et al.*'s (2008) research on professional learning communities shows how group work improves instructional design by fostering shared knowledge.

In classroom practices, the teachers' NOS understanding influenced their instructional approaches, with varying success based on their grasp of NOS concepts. Teachers with a more robust NOS understanding, developed through the PD, were more adept at emphasizing NOS in their teaching, often using inquiry-based questioning (e.g., "How do scientists share their findings?") and real-life examples (e.g., discussing the role of international research centers) to highlight dimensions like SI and AV. This aligns with Akerson *et al.*'s (2007) findings, where teachers with strong NOS understanding effectively embedded epistemic discussions in lessons. In this study, teachers needed continuous feedback from the researcher to improve how they focused on NOS. This was clear during reflection sessions, where they discussed how NOS was often separated from the lesson, showing that their learning process was slower and more step-by-step. This gradual progress is also noted in Saad and BouJaoude's (2012) study, which found that iterative feedback is crucial for teachers transitioning to NOS-focused teaching, though the current study's online format introduced additional challenges in sustaining this feedback loop.

Teaching SK and M categories proved particularly challenging, as these were perceived as theoretically complex. Teachers struggled to explain concepts like theories versus laws or scientific methods to younger students, often finding these categories abstract and difficult to contextualize. Consequently, they generally preferred to SP, AV, and SI categories of RFN in their MIX1 and MIX2 lesson plans. This study shows that teachers' understanding of NOS affected how they taught in the classroom. Teachers generally had difficulty learning the M and SK categories compared to others. They had more misconceptions about these categories before the intervention. Hence, teachers might need special teaching strategies to teach these categories. Also, teachers who knew their science topics well, like atomic structure, found it easier to add NOS to their lessons. The findings match studies (Hanuscin *et al.* 2011; Wahbeh and Abd-El-Khalick, 2023) that teachers need to know both NOS and science topics well to teach NOS properly. Another study by Demirdöğen *et al.* (2016) agrees, saying teachers need help, like step-by-step guides, to teach hard NOS ideas, just like the teachers in this study struggled with SK and M.

The sharing of classroom experiences with peers during session 3 was transformative, allowing teachers to identify strengths and weaknesses in their lessons (e.g., high engagement via simulations, issues with time management) and consider improvements

(e.g., simplifying visuals like Brandon's Matrix). This reflective practice aligns with Vescio *et al.*'s (2008) findings on PLCs, where continuous dialogue enhances teaching effectiveness, though the current study's online context introduced additional benefits, such as broader peer perspectives across different schools, and challenges, like managing virtual discussions. Additionally, Min *et al.*'s (2020) study on NOS PD emphasizes that reflection improves long-term pedagogical growth, which the current study can positively influence their future practices (e.g., better time allocation, simplified NOS visuals).

5.3. Science Teachers' Reflection on Online Collaborative Reflective PD Program

The six science teachers in the current study provided a diverse array of insights into their experiences with the online, collaborative, and reflective PD program structured by the RFN framework, revealing both shared and individual perspectives on its impact on their NOS understanding and teaching practices. Collectively, the teachers appreciated the program's collaborative structure, emphasizing how group activities like poster preparation and article discussions fostered creativity and diverse perspectives, aligning with Crotty's (2024) findings on collaborative reflection enhancing teaching innovation. They particularly valued the exchange of practical ideas, such as using LEGO or structured small-group tasks, which enriched their instructional strategies on the role of peer interaction in NOS learning. However, some teachers noted challenges with group dynamics, suggesting grade-level grouping or highlighting hesitancy in lesson plan critiques due to time constraints, reflecting a divergence from Vescio *et al.*'s (2008) emphasis on sustained collaboration and indicating logistical barriers in online settings.

In terms of NOS learning, the program significantly deepened understanding for most teachers, correcting prior misconceptions, such as the belief that theories turn into laws or superficial undergraduate NOS exposure. This aligns with Abd-El-Khalick's (2013) findings on explicit-reflective PD addressing NOS misunderstandings, though some felt they needed more time to internalize RFN categories, a nuance less explored in Abd-El-Khalick's study. Others appreciated the RFN framework's structured visualizations, noting its holistic approach and practical engagement, echoing McMinn *et al.*'s (2021) emphasis on structured, hands-on PD boosting self-efficacy. However, challenges in translating theoretical NOS understanding into practice, particularly with scientific knowledge and methods, were

evident, a difficulty also noted by Aydın *et al.* (2012) among Turkish teachers facing curriculum constraints, underscoring the need for more contextual support in PD programs.

The teachers' views on the program's structure revealed both strengths and areas for improvement. Many found the program engaging but exhausting due to scheduling conflicts, suggesting earlier sessions or pre-shared materials to suit active learning styles, highlighting a need for flexibility not fully addressed in Crotty's (2024) intensive PD model. Some appreciated the content's alignment with national standards, proposing more time for lesson planning or a longer duration for deeper reflection, aligning with Vescio *et al.*'s (2008) call for sustained PD but contrasting with Wahbeh's (2009) shorter, intensive approach. The suggestion for a backup teacher system to address absences underscores a practical challenge unique to online PD, differing from the face-to-face focus in Charalambos *et al*. (2004) emphasizing the need for adaptive strategies in virtual settings.

Collaboration was a double-edged sword across the group. Many found it enriching, valuing complementary strengths and balanced contributions in small groups, supporting Mertinez *et al.*'s (2017) findings on collaborative learning benefits. However, others faced challenges, noting dominant personalities limiting input or resource disparities complicating teamwork, a nuance less emphasized in Vescio *et al.* (2008) but reflective of Aydın *et al.*'s (2012) findings on systemic collaboration barriers in Turkish contexts. Teachers with limited prior collaboration experience in private institutions found the program a significant shift, with journals highlighting mutual support, aligning with Crotty's (2024) emphasis on peer learning, though logistical issues like time constraints occasionally hindered effectiveness, pointing to a need for better group composition strategies.

The teachers' suggestions for future PD programs reflect a collective desire for inclusivity and practicality. Suggestions to streamline lesson plan presentations and focus on grade-level grouping highlight the need for tailored collaboration, a concept supported by Vescio *et al.* (2008) but complicated by online PD's unique challenges, such as absences and scheduling. The emphasis on more time and active engagement aligns with McMinn *et al.*'s (2021) findings on the importance of practical, hands-on PD, though struggles with school culture and curriculum demands reflect broader systemic issues noted by Aydın *et al.* (2012), indicating a need for structural support in Turkish education contexts.

Overall, the teachers' experiences underscore the transformative potential of online, collaborative, and reflective PD in enhancing NOS understanding, as supported by Crotty (2024) and Bayar (2014). Their shared appreciation for peer interaction and practical engagement aligns with Vescio *et al.*'s (2008) findings on collaborative benefits, yet challenges like the need for more internalization time, group dynamic issues, and logistical concerns highlight the need for flexible, context-specific PD designs. These findings, contextualized within the Turkish education system, resonate with Aydın et al.'s (2012) call for tailored PD, suggesting that while the program was effective, addressing scheduling, group composition, and systemic barriers could further enhance its impact on NOS teaching practices.

5.4. Limitations of the Study

This multiple case study has several limitations, both methodological and practical in nature. One of the traditional criticisms of case study research, as outlined by Yin (2014), concerns the need for greater rigor, the limited generalizability of findings, the potential for lengthy and dense documentation, and the unclear comparative advantage of case studies relative to other research methods. These issues primarily relate to the consistency, credibility, and transferability of findings. Although such concerns can be mitigated when the nature of the case study is properly understood and trustworthiness is ensured throughout the research process (Merriam, 1998), they still pose inherent challenges.

Additionally, the small sample size (six participants) restricts the scope of generalization. The timing of the PD sessions also created limitations; since the sessions were scheduled between 19:00 and 21:00 to accommodate the teachers' availability after school, participants were often tired, which reduced their engagement and productivity. Teachers were expected to implement the lesson plans they developed during the week; however, unexpected school events such as trips or exam weeks sometimes created anxiety about fulfilling this requirement. Despite this, only one teacher was unable to complete an implementation. Furthermore, the 120-minute session allocated for collaborative lesson planning was insufficient for some groups, resulting in rushed or superficial feedback. Due to time constraints, there was little opportunity for revisiting or refining the plans in later

sessions. Moreover, greater flexibility in the scheduling of lesson planning and reflection sessions could have improved the depth and quality of the work produced.

6. IMPLICATIONS

In this section, implications for teacher education programs, teachers' professional development programs, and future research are provided.

6.1. Implications for the Teacher Education Programs

The integration of NOS teaching into pre-service teacher education is critical due to the lasting impact of knowledge acquired during undergraduate studies. Research indicates that intervention studies on NOS understanding significantly enhance teachers' professional development and practical implementation for both pre-service and in-service teachers (Cofré *et al.*, 2019; Kaya *et al.*, 2019). However, current NOS courses at the undergraduate level are often superficial, resembling general teaching methods courses and failing to equip teachers with the skills to effectively integrate NOS into their classrooms. This lack of depth can lead to misconceptions, particularly regarding the diversity of scientific methods and the distinctions among types of scientific knowledge. To address this, pre-service education programs must offer comprehensive NOS courses that include explicit teaching strategies and practical applications, ensuring teachers develop a robust and realistic understanding of NOS that they can confidently apply in their teaching practices.

Incorporating practical components, such as reviewing and developing lesson plans, is essential for pre-service NOS education. Studies showed that teachers wanted to see example lesson plans, examples, teaching materials, and curriculum-adapted objectives for the incorporation of NOS (Kurt and Kaya, 2024). Moreover, in the current study, teachers with prior exposure to NOS components, such as those within the RFN framework, demonstrated greater improvement in their NOS perceptions and teaching practices (Leyla and Melisa). This underscores the importance of early and thorough NOS instruction in pre-service programs, enabling teachers to design more effective, context-specific lesson plans that account for diverse student profiles and school resources, such as differences in class size, laboratory equipment, and facilities between private and public schools (Aksöz, 2019).

The effectiveness of NOS teaching is also influenced by its integration into curricula and assessments (Kurt and Kaya, 2023; Okan and Kaya, 2023). Teachers with a strong NOS foundation from pre-service education are better equipped to incorporate NOS into their instruction when curricula emphasize it (Demirel *et al.*, 2023). However, without explicit curricular support, even teachers with informed NOS views may struggle to translate their understanding into classroom practice. To maximize the impact of NOS education, teacher preparation programs should prioritize in-depth, application-oriented courses and advocate for NOS inclusion in national curricula. By fostering a comprehensive understanding of NOS and providing practical teaching experience, pre-service programs can empower future teachers to effectively integrate NOS, ultimately enhancing students' scientific literacy and understanding of the scientific enterprise.

6.2. Implications for the Teachers' Professional Development Programs

Professional development programs aimed at enhancing science teachers' understanding of the NOS should be strategically designed by incorporating key elements identified as effective PD programs. First, conducting detailed needs analyses is essential to tailor PD content to the specific requirements of teachers, considering their discipline, teaching experience, and prior NOS knowledge. Training programs should be based on the RFN approach, as this framework offers a comprehensive view of the scientific enterprise that aligns well with the diverse needs of teachers (Erduran and Dagher, 2014). In addition, PD activities should be grounded in practice and include opportunities for teachers to apply NOS concepts in lesson planning and classroom contexts, contributing to both their pedagogical content knowledge (PCK) and NOS understanding (Cullinane and Erduran, 2022). Programs that promote collaborative and reflective learning environments have been shown to help teachers develop more holistic perspectives on science education (Kaya *et al.*, 2019). Furthermore, online and flexible formats of PD, especially those supporting peer collaboration and reflection, should be expanded to increase accessibility and engagement. Given the challenges in fostering collaborative teaching cultures within Turkish schools, efforts should also focus on creating more supportive institutional environments. Finally, integrating NOS into broader aspects of teacher knowledge, such as NOS for PCK, through practice-based, iterative training sessions can further bridge theory and practice. Such

improvements will contribute to strengthening NOS instruction within the Turkish educational context.

6.3. Implications for Future Research

Future research could benefit from expanding the participant pool to include a larger and more diverse sample of teachers from various regions of Turkey, not just from Istanbul, to enhance the representativeness and generalizability of the findings. Including teachers from different science disciplines, such as physics, chemistry, and biology, may also provide deeper insights into discipline-specific needs and perspectives regarding the NOS. Moreover, conducting longitudinal studies would allow researchers to investigate the long-term impact and retention of PD outcomes. Since most participants in the present study were master's students, future studies may consider working with teachers at varying educational levels and degrees of professional experience, including those with over ten years of teaching experience. This could shed light on how career stage and academic background influence teachers' engagement with and development of NOS understandings. Lastly, scheduling PD programs on weekends or ensuring participants are officially excused from their teaching duties during the training days could help mitigate the effects of fatigue and increase the overall effectiveness of such programs.

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APPENDIX A: VISUAL REPRESENTATIONS

Visualize the associations these concepts make for you and explain the drawings in the columns next to them.

Table A.1. Visual representation of science.

Aims and values of science	Explanation of the visual
Scientific methods and methodological rules	Explanation of the visual
Scientific practices	Explanation of the visual
Scientific knowledge	Explanation of the visual
Social-institutional aspects of science	Explanation of the visual

APPENDIX B: INTERVIEW PROTOCOL BEFORE THE PD PROGRAM

INTERVIEW PROTOCOL BEFORE THE PD PROGRAM

1. Can you give information about yourself in general and following issues?
    - Educational background, teaching year, school type
    - Your students and school environment, resources, materials
    - Teacher education activities
2. What is your approach to teaching science in general?
    - Could you describe your typical teaching style?
    - How do you prepare your lessons?
    - Do you have any major teaching practices, strategies, or methods that you adopt and use? Why did you choose this method?
3. Could you inform me about your lesson plans you have in general?
    - What kind of lessons plan do you prepare?
    - What do these lesson plans include? (Materials, interactions, assessment)
    - If you are doing activities, what kind of activities would you prefer?
4. What do you think about your learning?
5. What kinds of teacher training activities do you think are more beneficial?
6. What do you think about teachers' collaborative work? Do you have any experience about collaborative work with your colleagues? How?
7. What are your expectations regarding to this PD program?
8. Do you have any concerns about the implementation of PD program?
9. What does it mean for you "nature of science"?
10. What do you think about teaching NOS in science lesson in general and for you?
11. What do you think about NOS emphasis in science curriculum?
12. What does it mean following terms for you? Do you refer/teach these terms of science in your science lessons? How?
    - aims and values of science
    - scientific practices
    - scientific methods and methodological rules
    - scientific knowledge
    - social-institutional aspects of science
13. How would you evaluate your science teaching in your classes in general?
14. What do you think about your strengths and weaknesses about teaching science?
15. What do you think about the factors that affect your science teaching efficacy?
16. How do you see yourself in teaching NOS in your lessons?

APPENDIX C: INTERVIEW PROTOCOL AFTER THE PD PROGRAM

INTERVIEW PROTOCOL AFTER THE PD PROGRAM

1. You participated an online PD program on the NOS that lasted about 2 months. Do you think NOS should be taught in science lessons? Why?
2. How much do you think NOS categories are integrated into science lessons?
3. Do you think it is possible to teach NOS categories in science lesson?
4. What does it mean following terms for you? Do you refer/teach these terms of science in your science lessons? How?
   - aims and values of science
   - scientific practices
   - scientific methods and methodological rules
   - scientific knowledge
   - social-institutional aspects of science
5. How do you think the PD program on NOS went? What do you think the strong and weak aspects of the PD program?
6. During the NOS training, you did various group work (poster preparation, lesson plan analysis, discussion, lesson plan preparation). What do you think about collaborative work in teacher education?
7. If this PD program was to be done again, what would you say to "keep it the same and change"?
8. What do you think how this PD program has developed you, how do you plan to integrate NOS into your lessons from now on?
9. What do you think about the effects of PD program on your lesson plans?
10. What do you think about the effects of PD program on your classroom practices?
11. How would you evaluate your science teaching after the PD program?
12. How do you see yourself in teaching NOS in your lessons after the PD program?
13. Do you think online PD program structured by RFN framework has an effect on your science teaching efficacy?

APPENDIX D: LESSON PLAN FORMAT

DERS PLANI FORMATI

Grup üyelerinin isimleri:

Sınıf seviyesi:

Ünite adı:

MEB kazanımları:

RFN kazanımları:

Öğrencilerin ön bilgileri:

Ders süresi:

Öğretim teknikleri:

Materyaller:

Ders planı özeti:

1. *Giriş*
2. *Keşfetme*
3. *Açıklama*
4. *Derinleştirme*
5. *Sonuç*

Değerlendirme:

Kaynakça:

APPENDIX E: LESSON PLAN ASSESSMENT RUBRIC

Group Members: RFN Category: Date:

This rubric is prepared for assessing the lesson plans produced through the online reflective/collaborative professional development program structured by RFN framework. There are ten criteria to assess the quality of the lesson plan. If the quality is considered *unsatisfactory*, 1 point is given. If it is considered *fair,* 2 points is given, and if it is considered *good*, 3 points is given.

Table E.1. Rubric for lesson plan development.

Criteria	**Unsatisfactory (1)**	**Fair (2)**	**Good (3)**	**Points**
1. The lesson plan explicitly states MoE learning objectives.				
2. The lesson plan explicitly states RFN learning objectives.				
3. All stated RFN objectives are covered in the lesson plan / all taught RFN objectives are explicitly listed in the RFN objectives section.				
4. The lesson plan clearly describes prior knowledge of the students.				
5. The lesson plan clearly describes procedures.				
6. The activity in integrating of RFN category to the scientific topic is appropriate.				
7. The RFN category is referred at least two parts of the lesson plan.				
8. The lesson plan includes variety of resources/materials integrating technology.				
9. The lesson plan promotes active engagement of students. (Group activity: 3; QA: 2)				
10. The lesson plan includes a variety of instructional techniques.				
11. The lesson plan includes appropriate assessment methods.				
12. RFN objectives are assessed during the assessment part of the lesson.				
13. The lesson plan is instructionally appropriate in terms of time management.				
Total Score:				

APPENDIX F: JOURNAL ENTRIES

JOURNAL ENTRIES

Evaluation of weekly workshop

1. What was the workshop topic of the week?
2. What do you think about the importance of weekly workshop topic in science education?
3. Do you think the workshop was meaningful for you? Why do you think so?
4. How were your group discussions during the workshop?
5. What do you think about the effectiveness of cooperative activities during the workshop?
6. Could you evaluate the PD program since this week? (for 5th and 10th week)

Incorporation of NOS activities to lesson plan

7. How did you integrate RFN to your lesson plans?

Why did you choose this teaching practice, strategy, or method?

8. Did you have some challenges to integration of RFN to your lesson plans?

Teaching of NOS

9. What did go well with the lesson?
10. Was there anything unexpected during the instruction?
11. Would you like to change anything about the activities if you were doing them for a second time?
12. Do you think the students were able reach learning goals? How do you know?
13. Do you think the lesson was meaningful for them? Why do you think so?
14. Could you evaluate your teaching practice considering the weekly RFN category?

APPENDIX G: CLASSROOM OBSERVATION PROTOCOL

Öğretmen: **Sınıf seviyesi:**

Konu: **Öğrenci sayısı:** **Tarih/Süre:**

Her bir gösterge altında, öğretmenin bu derste gözlemlediği davranışlarını veya öğretim unsurlarını aşağıdaki ölçeğe göre derecelendiriniz.
3 = Örnek: Öğretmen bu alanda tutarlı ve etkili bir beceri sergilemiştir; adayın performansı beklenenin ötesine geçmiştir.
2 = Yeterli: Öğretmen, bu alanda, bu düzeyde beklenebilecek bir beceri sergiledi; beklentiler karşılandı.
1 = İyileştirme Gerekiyor: Öğretmen, bu alanda beceri gösterme potansiyeline sahiptir, ancak daha fazla uygulamaya ihtiyaç vardır.
0 = Yetersiz: Öğretmen, beceriyi geliştirmedi ve çok fazla iyileştirme gerekiyor.

Table G. 1. Classroom observation protocol.

Öğretim	**Öğretim Etkinlikleri**	**Değerlendirme**
	Kavramlar ve prosedürler doğru ve kendinden emin bir şekilde sunulur.	
	Sorgulama ve geri bildirim, düşünmeyi ve katılımı teşvik etmek için kullanılır.	
	Öğretim, öğrencilerin bilgi ve gelişim düzeyleri üzerine kuruludur.	
	Etkinlik bilimin doğası kategorisinin bilimsel konuya entegrasyonu noktasında uygundur.	
	Bilimin doğası kategorisinin bilimsel konuya entegrasyonunda uygun stratejiler kullanılır.	
	Sınıf ve Zaman Yönetimi	**Değerlendirme**
	Yönetim uygulamaları riskleri öngörerek uygulanmıştır.	
	Tüm öğrencilerin etkin katılımını sağlamak için uygun stratejiler kullanılır.	
	Öğretmen etkinlikler arasında yumuşak geçişler yapar.	
	Değerlendirme (Biçimlendirici ve Özetleyici)	**Değerlendirme**
	Ders, öğretilen bilimsel içeriği değerlendirir.	
	Ders, bilimin doğası kazanımları için uygun değerlendirme yöntemlerini içerir.	
	Prosedürel anlamanın yanı sıra kavramsal anlamaya odaklanmak için değerlendirmenin net bir kullanımı vardır.	
	Öğretmen, öğrencilerin öz-yansıtmalarını teşvik eder ve destekler.	
Yansıtma	**Yansıtma**	**Değerlendirme**
	Öğretmen ders uygulamasının iyi ve kötü yönlerini ifade eder.	
	Öğretmen, bilimin doğası entegrasyonu açıklar.	
	Öğretmen, öğrencilerin öğrenmelerini değerlendirir.	
	Öğretmen, dersi geliştirmesi için gerekli yöntemleri ifade eder.	
Puan		…….. /48

APPENDIX H: EXAMPLE LESSON PLAN

DERS PLANI (MIX 1)

Grup 3 üyelerinin isimleri: Deniz, Leyla

Sınıf seviyesi: 7. Sınıf

Ünite adı: Saf Madde ve Karışımlar

MEB kazanımları:
F.4.1.3. Aynı veya farklı atomların bir araya gelerek molekül oluşturacağını ifade eder.

Bilimin doğası kazanımları:
-Bazı bilimsel kavramları gözlemlemenin ve çalışmanın zorluğunu aktararak bilimsel çalışmalarda modellemenin rolünü açıklar.
-Öğrenciler, bilimsel çalışmaların sonuçlarının paylaşılmasının önemini açıklar.
-Öğrenciler, etkinliklerinde kullandıkları bilimsel yöntemleri Brandon'un Matrixinde gösterir.

Öğrencilerin ön bilgileri:
F.7.4.1.1. Atomun yapısını ve yapısındaki temel parçacıkları bilirler.

Ders süresi: 40 dk.

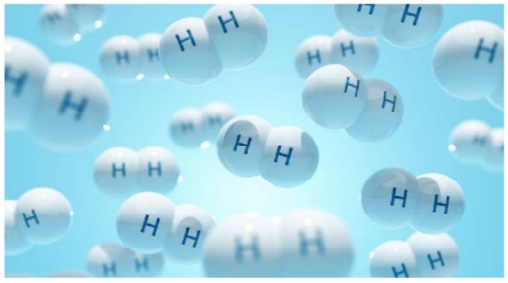
Öğretim teknikleri: Soru-cevap, Beyin fırtınası, Model, Açıklama, Tahmin

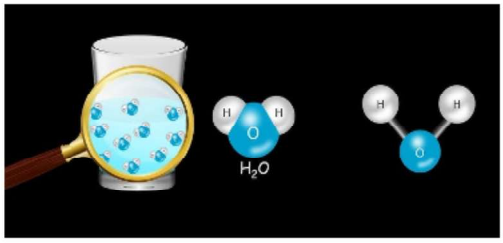
Materyaller: Etkinlik kâğıdı, slayt

Ders planı özeti:

1. Giriş:
Aşağıdaki soru sorularak beyin fırtınası yapılır.
Soru 1: Maddeler tek tür atomlardan mı oluşur yoksa farklı atomlar bir araya gelerek mi maddeleri oluştururlar?

Günlük hayattan iki örnek sunularak Soru 1 öğrencilere tekrar yöneltilir ve açıklamaları alınır.





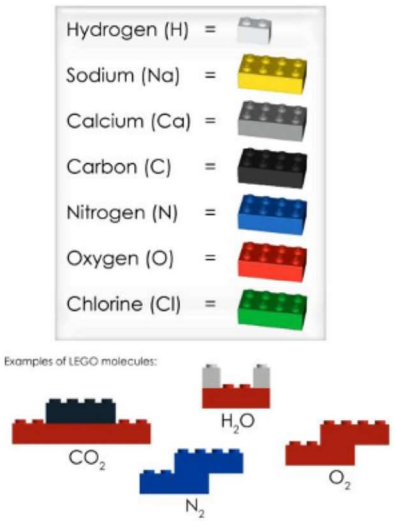
Aşağıdaki lego benzetmesi sunularak öğrencilerden CO2, H2O, N2 molekülleri ile yukarıdaki örnekler arasında benzerlik ilişkisi kurulması istenir.

CO2: Karbondioksit gazı

H2O: Su

N2: Azot gazı

O2: Hidrojen gazı

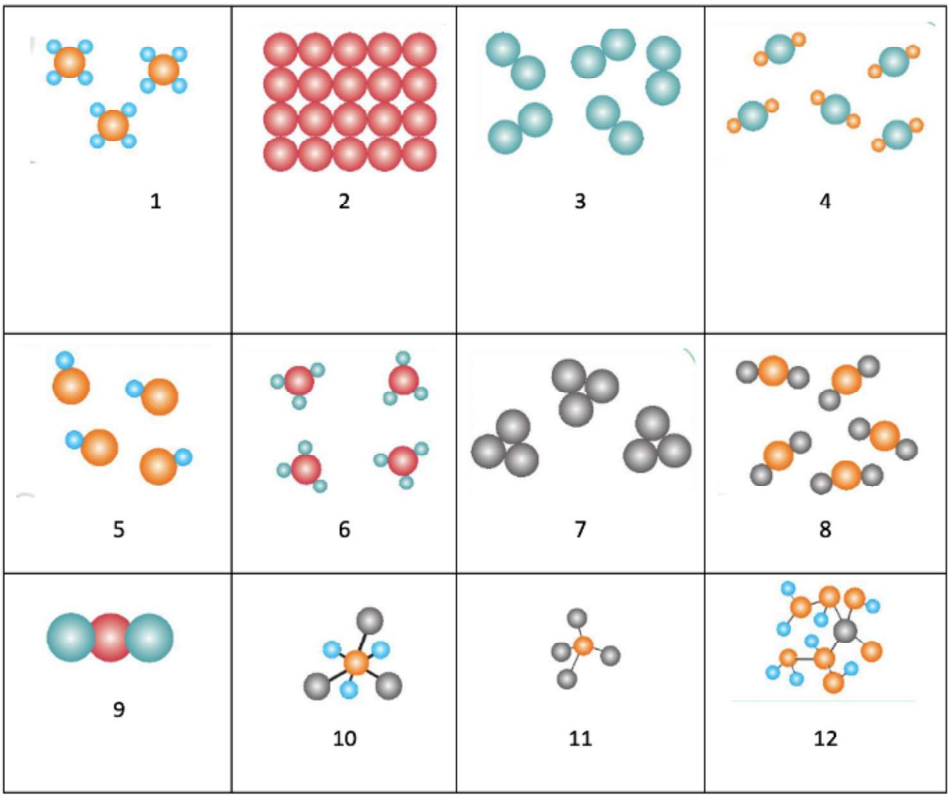


Molekül kavramı açıklanır: Aynı ya da farklı cins atomların bir araya gelerek oluşturdukları atom gruplarına molekül denir.

2. Gelişme:

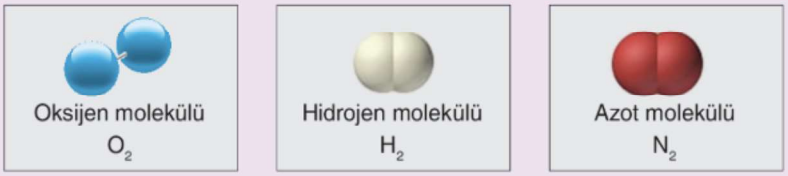
Bugün sizin önemli bir göreviniz var. Laboratuvarda incelenmiş bazı maddelerin molekül modellemeleri bilim insanları tarafından oluşturulmuş ancak moleküllerin sınıflandırılması yapılmamıştır. Yarın bilim heyeti gelerek sınıflandırmayı inceleyecektir. Sizden bu molekülleri en uygun şekilde sınıflandırmanız ve sunuma hazır hale getirmeniz beklenmektedir.

12 tane molekül modeli bulunmaktadır. Molekülleri uygun şekilde sınıflandırınız.

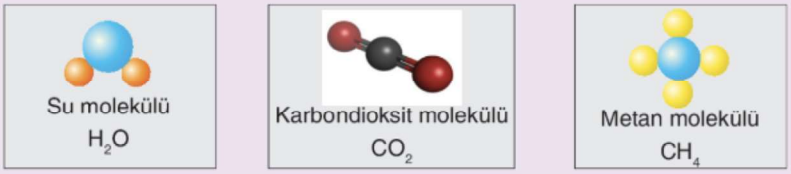


10 dk süre verilir. Süre bitiminde öğrencilerden sınıflandırmaları istenir.

Aynı cins atomların bir araya gelerek oluşturdukları gruba **element molekülü** denir.



Farklı cins atomların bir araya gelerek oluşturdukları gruba **bileşik molekülü** denir.

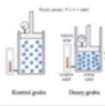
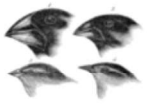
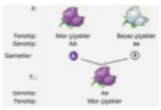


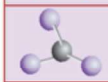
Bilim insanları molekülleri aynı cins ve farklı cins atom içerme durumlarına göre sınıflandırmışlardır. Bu şekilde sınıflandırma yapanlar heyet onayını almıştır.

3. Sonuç

Soru 1: Çalışmalarımız süresince moleküller modellemeler sayesinde temsil edildi. Niçin moleküller modelleme bilimsel pratiği kullanarak incelenmiştir?
Soru 2: Molekülleri sınıflandırmak ne tür yararlar sağlar?
Soru 3: Sınıflandırma çalışmasının bilim heyetine sunulmasının önemi nedir?
Soru 4: Bilim heyeti sınıflandırmanızı ve açıklamalarınızı değerlendirirken sizce hangi kriterlere dikkat edecektir?
Soru 5: Bilimsel çalışmalarda çeşitli bilimsel yöntemler uygulanır. Brandon'ın Matrixinde görebileceğiniz gibi bazı bilimsel çalışmalar hipotez test etme ve değişken değiştirme açısından çeşitli yöntemler kullanırlar. (Öğretmen örnekleri kısaca açıklar.) Bugün yaptığımız bilimsel çalışma buradaki örneklerden hangisine benzemektedir?

Brandon'un Matrixine Örnekler

	Manipülasyon yapmak (Değişken değiştirmek)	**Manipülasyon yapmamak (Değişken değiştirmemek)**
Hipotez test etmek	 H_0= Basınç ve hacim arasında ters bir ilişki vardır.	 H_0= Kuşların gaga şekilleri ile beslenmeleri arasında ilişki vardır.
Hipotez test etmemek	 Saf dölleri birbirleriyle çiftleştirerek özelliklerin nasıl aktarıldığı incelendi.	 Kopernik'in Güneş merkezli modeli çok sayıda dikkatli astronomik gözlemden geldi.

	MOLEKÜL MODELİ	ELEMENT MOLEKÜLÜ	BİLEŞİK MOLEKÜLÜ	ATOM ÇEŞİDİ SAYISI
1				
2				
3				
4				
5				

Kaynakça: