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SI: FAMILY RESEMBLANCE APPROACH

How is Students' Understanding of Nature of Science Related with Their Metacognitive Awareness?

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Abstract

The paper reports an empirical study on the relationship between middle school students' understanding of nature of science (NOS) and their metacognitive awareness. The reconceptualised family resemblance approach to the nature of science (RFN) (Erduran & Dagher, 2014; Kaya & Erduran, 2016) as a holistic framework that covers science as epistemic-cognitive and social system guided the study. A total of 701 students (180 5th, 167 6th, 170 7th, and 184 8th grade) and 3 students from each grade level (in total 12 students) who have low, moderate, high-RFN understanding, and metacognitive awareness levels were interviewed. The data sources are the "RFN Student Questionnaire," "Metacognitive Awareness Inventory for Children," and interviews. The data was analyzed with Pearson product-moment and thematic analysis. The results indicated that there is a statistically positive relationship between middle school students' RFN understanding and their metacognitive awareness. Furthermore, the results of the interviews showed that students' responses to RFN and metacognitive awareness questions were aligned and compatible. The students with high metacognitive awareness had higher RFN understanding and those with lower metacognitive awareness had lower RFN understanding. This relationship was evident for each grade level student separately as well. The study opens a new study area in terms of the use of metacognitive strategies in RFN-enriched lessons for experimental and causal-comparative designs. The teacher education programs or curriculum studies can consider utilization of metacognitive prompts in NOS teaching.

1 Introduction

For several decades, the nature of science (NOS) became a critical context in science education. It was associated with epistemology and the sociology of science (Lederman et al., 2002). In NOS education, learners become critical and scientifically literate citizens with understanding values of science, scientific enterprise, science process skills, generation of

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scientific knowledge, etc. (Jimenez-Aleixandre et al., 2000; Olson, 1998). In this respect, understanding NOS is a critical goal for science education (NGSS Lead States, 2013).

Several approaches and views are proposed for the definition of NOS in science education. The most studied and outstanding perspective is "Consensus View" which introduces the seven tenets of NOS. Other approaches are "Whole Science" (Allchin, 2011), "Features of Science" (Matthews, 2012), "Family Resemblance Approach (FRA) to NOS" (Irzik & Nola, 2014), and "Reconceptualized Family Resemblance Approach to NOS" (Erduran & Dagher, 2014). However, many critiques and issues have been concerned with the definition of NOS in science education. For instance, the lack of historical, philosophical, epistemic, and psychological aspects of science in consensus view have been criticized (Matthews, 2012). The epistemic components of science, functional analysis of scientific literacy (Allchin, 2011; Hodson & Wong, 2017) and socio-cultural and domain-specific features of science (Erduran & Dagher, 2014; Irzik & Nola, 2014) were neglected with distorting the meaning of the nature of science.

The recent and holistic account needs to emerge with the inclusion of epistemic-cognitive and social aspects of science (Erduran & Dagher, 2014). Erduran and Dagher (2014) characterized science with 11 categories which are aims and values of science, scientific practices, scientific knowledge, methods and methodological rules, scientific ethos, social certification and dissemination, social values, professional activities, political power structure, financial systems, and social organizations and institutions categories. Erduran and Dagher's (2014) family resemblance approach (FRA) to NOS embodies educational suggestions, utilizes domain-specific perspectives of science, and provides visual dynamic tools for NOS education. In a later paper (Kaya & Erduran, 2016) a new coined term, reconceptualized FRA-to-NOS (RFN) has been attributed for this framework to highlight its utility in educational implications. Thus, the theoretical basis of this study is based on this approach, and RFN term is used to refer this approach throughout the paper.

For learning and understanding NOS, students need to have consciousness on their thinking and learning process with evaluating and monitoring scientific ideas. They should be aware of how they learn, form, and articulate main NOS concepts, terms, and processes (Baraz, 2012; Peters & Kitsantas, 2010; Peters-Burton & Burton, 2020). In this respect, it is apparent that metacognition has influential agenda over the nature of science education. For instance, for consciously controlling the science process skills, students need to monitor their thinking process and are aware both physically and cognitively (Thomas, 2011). Hence, understanding students' scientific ideas, enhancing their thinking strategy, and making them aware of their own learning process are some of the critical points that need to be practiced in NOS education (Beeth & Hewson, 1999; Peters-Burton & Burton, 2020). From this perspective, NOS and metacognitive awareness can be linked and it is essential to understand students' metacognitive awareness in their learning process in the NOS context.

Understanding the relationship between metacognitive awareness and NOS understanding is critical for the inclusion or use of metacognitive strategies or techniques in science classrooms to benefit students' NOS learning. The studies (Akerson & Donnelly, 2008; Cetinkaya-Aydın & Cakıroglu, 2017; Gulsuyu, 2019) also show the place of metacognition and metacognitive awareness (MA) in NOS learning. For instance, when these metacognitive skills and techniques have been practiced in science lessons, students' NOS understanding enhance (Peters & Kitsantas, 2010). In RFN context, some studies concentrate on middle school students (Akbayrak & Kaya, 2020; Cilekrenkli & Kaya, 2022). However, there is a gap in terms of examining the relationship between students' RFN understanding and their metacognitive awareness. Thus, this relationship study paves the way for appraising the link of students' NOS understanding with their metacognitive awareness which has the potential to lead utilization of metacognitive strategies for teaching NOS in science lessons. The current study aims to examine the relationship between middle school students' RFN understanding and their metacognitive awareness for each grade level student (5^{th}, 6^{th}, 7^{th}, and 8^{th}) separately by using quantitative and qualitative approaches. The addressed research questions are as follows.

Research Question 1: Is there a statistically significant relationship between middle school students' understanding of RFN and their metacognitive awareness?
Research Question 2: How does the relationship between students' understanding of RFN and their metacognitive awareness differ among 5^{th}, 6^{th}, 7^{th}, and 8^{th} graders?

2 Theoretical Framework

2.1 The Reconceptualised Family Resemblance Approach to the Nature of Science (RFN)

The recent and contemporary framework that encapsulates categories of science as an epistemic-cognitive and social institutional system is Erduran and Dagher's version of FRA to NOS (Erduran & Dagher, 2014). The origin of FRA to NOS (Irzik & Nola, 2011) comes from the idea of family resemblance that is originated by Wittgenstein (1958) with defining similar and dissimilar characteristics of different science disciplines like family members. Irzik and Nola (2011) adapted this idea for NOS from philosophical definitions and theoretical perspectives. Erduran and Dagher (2014) extended Irzik and Nola (2014)'s approach with additional categories (scientific practices, political power structures, financial systems, social organizations, and interactions), visual dynamic tools, and pedagogical perspectives. Their framework utilizes concrete examples for curriculum implications and domain-specific features of science. Later, authors (Kaya & Erduran, 2016) used the reconceptualized FRA-to-NOS (RFN) term this framework while separating it from the previous versions with emphasis on the educational perspectives and empirical adaptations.

Erduran and Dagher (2014) proposed 11 categories of science comprehensively in which each category has a mutual interaction and interrelation. They developed the "FRA Wheel" (see Fig. 1) as a holistic systematization of science, and it serves as a visual tool for learners and educators of NOS. In this wheel, four quadrants at the inner circle contain epistemic-cognitive categories (aims and values of science, scientific practices, methods and methodological rules, scientific knowledge) and the surrounding outer circle pertains to the social institutional system with social values, scientific ethos, social certification and dissemination, professional activities, political power structures, financial systems, and social organizations and interactions categories.

Aims and values constitute epistemic-cognitive dimensions such as fruitfulness, testability, and empirical adequacy, in addition to being free from inductive bias, honesty, equality, etc. (social dimensions) (Allchin, 1999; Kuhn, 1977). In scientific practices in the real world, prediction, explanation, data, and model incorporate in addition to classification, observation, and experimentation (Erduran & Dagher, 2014; Jimenez-Aleixandre et al. 2000). Methods and methodological rules refer to the work of various systematic

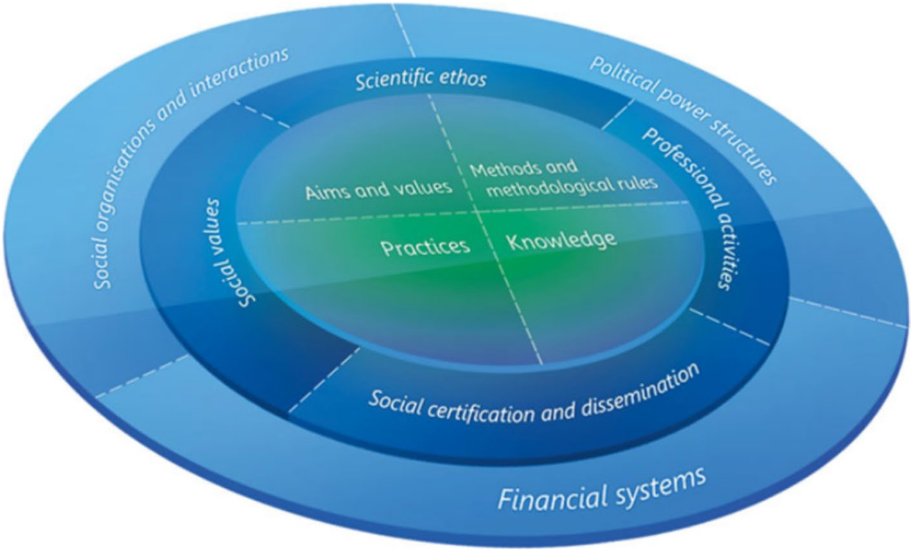

Fig. 1 FRA wheel: science as a cognitive–epistemic and social institutional system. Source: (Erduran & Dagher, 2014, p28)

procedures or rules (e.g., (non)manipulative methods, (in)direct observation) which function synergistically and lead to explanatory consilience (Wilson, 1998). Scientific knowledge embodies the emergence and growth of scientific knowledge with work of theories, laws, and models (TLM) (Erduran & Dagher, 2014) with domain-specific features (Duschl, 1994). The social institutional categories cover social values (e.g., respecting environments or animals, social utility) of ethical principles, the importance of certification and dissemination, professional activities of scientists (e.g., attending conferences), political power structures, financial system, and social organizations and institutions (Erduran & Dagher, 2014).

Moreover, RFN embodies neglected critical aspects such as domain-general and specific perspectives of science which allow learners to think around differences in disciplinary variations of each category of science for the reflective thinking process. Thus, these features of RFN add a metacognitive dimension and create metacognitive awareness among learners (Erduran & Dagher, 2014). Empirical studies on RFN also strengthen the importance and utility of this framework. For instance, the studies on the science curriculum (Cheung, 2020; Yeh et al., 2019), textbooks (Okan & Kaya, 2022; Yang et al., 2020) comparison of preservice teachers, teacher education (e.g., Cullinane, 2018; Erduran et al., 2021), higher education context (Akgun & Kaya, 2020), and experimental studies (Akbayrak & Kaya, 2020; Cilekrenkli & Kaya, 2022) constitute research background of RFN. In the middle school science, context enrichment of science lessons with RFN-based instruction improves students' NOS understanding (Cilekrenkli, 2019) and increases students' attitudes towards science (Akbayrak & Kaya, 2020). Nonetheless, these experimental studies focused generally on 5th grade level students.

In a broad sense, the metacognitive awareness construct in RFN context has not been in the focus of researchers. Thus, it is seen that limited research focuses on the relationship between these constructs. In this respect, investigating students' NOS understanding such as students' perceptions and ideas towards aims of science, scientific practices and knowledge, methods and social dimensions of science, and linking those dimensions with metacognitive awareness (e.g., awareness of learning process, ability to articulate metacognitive skills) are crucial in NOS education.

2.2 Middle School Students' NOS Understanding

One of the essential purviews of NOS education is helping students to understand NOS (Lederman, 2007). NOS education supports the development of scientifically literate people and critical citizens for socio-scientific issues (AAAS, 1990; Abd-El-Khalick, 2014). For the attainment of this aim, students should possess an adequate understanding of NOS, and elucidating students' NOS understanding is needed (NRC, 2012). In this respect, many studies target students' NOS understanding. The studies (Cofré et al., 2019) pointed out that students' learning about theory and law concepts, social, cultural aspects, and development of scientific knowledge are much more difficult to understand than other aspects and most students hold a naïve understanding of the aim of experiments, scientific knowledge, and the scientific method. They were mistakenly believing that theories are facts to be proven and one scientific method myth (Tao, 2003). In brief, many studies (Khishfe, 2008; Nehring, 2020) reports that naïve and uninformed understanding of NOS prevails among the majority of students.

Understanding students' naïve ideas on NOS led researchers to focus on effective or alternative teaching strategies Allchin et al., 2014). NOS-related constructs or factors that can influence students' conceptual development process in learning NOS have been in the focus of researchers (Akerson et al., 2000; Schwartz et al., 2004). For example, studies acknowledge NOS as a cognitive learning outcome (Schwartz et al., 2004). Many metacognitive processes and strategies such as monitoring, evaluation, and planning ones' knowledge and awareness about his/her own learning direct students' NOS learning process (Akerson et al., 2006). If the teacher leads critical thinking and knowledge acquisition through metacognitive stance context, students become engaged with scientific practices and elements of NOS more consciously (Crawford & Capps, 2018). In this way, students' own NOS learning process is promoted by enhancing their regulation of knowledge and control of their thinking which makes them familiar and aware of thinking about their own thinking process in NOS (Chiu & Duit, 2011; Choi et al., 2011). Thus, metacognition and students' metacognitive awareness have a crucial place in NOS education and metacognitive strategies have a tremendous effect according to the literature (Peters-Burton & Burton, 2020).

2.3 Metacognitive Awareness and NOS

The term metacognition has been proposed firstly by Flavell (1976) and Brown (1987) with making a distinction between metacognitive knowledge and skills. Metacognitive awareness refers to ones' own knowledge, awareness, and control of the learning process which are categorized with two components: knowledge of cognition and regulation of cognition (Schraw & Dennison, 1994). While knowledge of cognition (KC or KoC) refers to our understanding of how we learn and which tactics or procedures are most effective for us, the latter refers to a variety of activities that help our management processes such as planning, monitoring, and evaluating (Brown, 1987). From the literature, there is ample evidence on the power of metacognition in a way to improve science learning (Zohar & Dori, 2012). For instance, monitoring allows students to detect their faulty assumptions while evaluation is needed for efficient causal framing as constructing new science concepts (Grotzer & Mittlefehldt, 2012; Zohar, 2006). These students who plan, sequence, or monitor their learning process become metacognitively more aware and perform better in science than unaware learners (Schraw et al., 2012).

If the aim is teaching science more effectively, students' metacognitive awareness needs to be considered for enhancing and promoting the quality of science lessons (Annevirta & Vaurus 2006; Thomas & McRobbie, 2001). For instance, the study (Swanson, 1990) on 6th grade level students' problem-solving outcomes reported that students who have high metacognitive awareness are better at problem-solving in science concepts. In another study, Sarıbas et al. (2013) reported that metacognitive guidance enhances preservice teachers' science process skills and understanding of science. Therefore, the use of metacognitive skills develops students' conceptual understanding of science, their problem-solving skills, and their achievement (Swanson, 1990; Young & Fry, 2008). These are some basic outputs or effects of metacognition in science education.

In many areas of science education, researchers have been engaged with a great amount of work in the field of metacognition. For example, in STEM education (e.g., Dori et al., 2018), argumentation (e.g., Hofstein et al., 2008; Kuhn et al., 2013), socio-scientific areas (e.g., Hsu & Lin, 2017) elements of metacognition have been introduced and examined. However, its place and focus on NOS education stay rather limited and the majority of studies focused on metacognition as an explicit or reflective teaching approach. The studies (e.g., Abd-El-Khalick, & Akerson, 2009; Peters & Kitsantas, 2010) reported that utilization of metacognitive prompts benefits NOS learning. While learners engage with scientific practices and teachers possess a metacognitive stance, students' critical thinking process develops (Crawford, 2014; Crawford & Capps, 2018).

NOS education demands one's cognitive learning process in which learners construct scientific ideas, develop science process skills, and become aware of science procedures. Learners need to control and regulate their learning process by activating their cognitive understanding and metacognitive progress (Beeth & Hewson, 1999). Thus, students' metacognitive awareness such as knowing their own learning process, monitoring, and regulating thinking strategy while learning NOS become a critical point of concern from a science education perspective (Akerson & Donnelly, 2008). Moreover, the studies report that students who receive metacognitive-based instruction while learning NOS show informed views on NOS concepts and a better understanding of science concepts. For example, Abd-El-Khalick and Akerson (2009) investigated the influence of metacognitive training on preservice teachers' NOS understanding and metacognitive awareness. They found that participants who received metacognitive training obtained higher gains in all five aspects of NOS and high metacognitive awareness scores. In a similar study, Baraz (2012) utilized metacognitive activities such as reflections, discussions, and concept maps with explicit reflective NOS instruction in a preservice teacher education context. The researcher concluded that metacognitive strategies increase students' metacognitive awareness and provide substantial gaining in NOS understanding. These strategies or activities promote students' problem-solving skills and metacognitive awareness (Akben, 2018). In this way, students become metacognitively aware learners which affect their NOS learning outcomes.

The relationship or context of metacognitive awareness in NOS education has not been in the interest of researchers. Some studies (Akerson & Donnelly, 2008; Cetinkaya-Aydın & Cakıroglu, 2017) concern the relationship between learners' characteristics and NOS learning. For instance, Akerson and Donnely (2008) focused on the association between preservice teachers (PSTs)' metacognitive awareness, self-efficacy, attitudes toward science teaching, and NOS ideas. A similar study (Cetinkaya-Aydın & Cakıroglu, 2017) is interested in the relationship between PSTs' scientific inquiry understanding and faith/worldview schemas in addition to metacognitive awareness and NOS views. While Cetinkaya-Aydın and Cakıroglu (2017) reported that PSTs who had informed views have high metacognitive awareness in terms of both components of metacognitive awareness, Akerson and Donnely (2008) concluded that regulation of cognition component has not been related with PSTs' NOS views.

In the middle school science context, a similar study (Gulsuyu, 2019) examined the relationship between students' NOS understanding and their metacognitive awareness with quantitative perspective including other variables such as gender, academic achievement, and parents' educational level. The researcher concluded that metacognitive awareness is statistically related to NOS understanding (r= .306) and students' academic achievement. However, the nature of these studies relies broadly on quantitative measures and underlines the previous accounts of NOS. Moreover, specific focus on different grade level students is underrepresented in the context of similar studies (Gulsuyu, 2019) and limited research is evident in the holistic account of the nature of science and metacognitive awareness. With the articulation of multiple data sources and verbal reports, the current study will allow for getting in-depth investigation of students' ideas and awareness (Guskey, 2007).

The study has the potential to contribute to the literature from several points. Firstly, this study brings a new perspective and introduces the concept of metacognitive awareness in RFN education originally. Particularly, its epistemic-cognitive-social components (e.g., ideas on the wheel) encourage reflective thinking on science disciplines, critical judgment on the diversity of scientific methods, and evaluation of the knowledge that scientists produce. With exposure to these ideas and the practice of metacognitive perspectives students' NOS learning process can enhance through their developmental process and ages (Erduran & Dagher, 2014). In this respect, the study can inform the NOS curriculum and educators in terms of teaching NOS with epistemic-cognitive and social institutional dimensions with linking metacognitive dimensions. Hence, this potential benefit and rationale enrich the context of the current study.

Lastly, the correlational study itself is advantageous for researchers who wish to discover and understand metacognitive awareness in the NOS context firstly. It opens up experimental studies for further research and provides hypothesis testing (Polit & Beck, 2012). In this perspective, this mixed-method study guides further studies in terms of utilization of metacognitive strategies in RFN-enriched lessons and makes significant contributions in these perspectives. Therefore, the rest of the study will attempt to investigate the relationship between students' metacognitive awareness and their RFN understanding.

3 Method

3.1 Research Design

This explanatory sequential mixed study was carried out with a broader funded project which includes examining the relationship between middle school students' RFN understanding and their metacognitive awareness. The data was collected with quantitative data in the first phase which informed the selection of participants for the qualitative part (Creswell, 2012). In the second phase, the qualitative interviews were structured.

Within the scope of quantitative data, the correlational study design guided the study by focusing on all middle school students' scores (6th, 7th, and 8th grade). In addition, for another aim, each grade level student's RFN understanding and metacognitive awareness scores (5^{th}, 6^{th}, 7^{th}, and 8^{th} grade) were investigated separately. As such, we attempt to correlate middle school students' RFN understanding and their metacognitive awareness' scores. For this relationship, the variables that we are primarily interested in are students' RFN understanding (the dependent variable) and students' metacognitive awareness (independent variable) as continuous scores. On the other hand, the qualitative design has been utilized for a deeper examination of the individuals' RFN understanding and their metacognitive awareness separately. Thus, the relationship between these two constructs has been explored with individual interviews as well. Thus, interpretation of both quantitative and qualitative data-guided researchers for a holistic understanding and conclude about the scope of this relationship.

3.2 Research Sample

Totally 701 students who take formal education at Turkish public middle schools have attended the quantitative part of the study. In Turkey, middle school starts from 5^{th} grade until 8^{th} grade as compulsory education. The age of participants is 10 (5^{th} graders), 11 (6^{th} graders), 12 (7^{th} graders), 13 (8^{th} graders) correspondingly. Participants were selected within two successive steps for quantitative and qualitative parts. Firstly, with conveniently selecting three different schools 180 5^{th}, 167 6^{th}, 170 7^{th}, and 184 8^{th} grade students (totally 701) were sampled. Secondly, three students from each grade level (in total 12 students) were selected for interviews. Since the study defines the middle school student groups as 6^{th}, 7^{th}, and 8^{th} graders, this group was consisting of 521 students. The reason and detailed information for this selection was explained in the succeeding section.

First of all, students whose scores correspond to a high-moderate-low level in both "RFN Student Questionnaire" and "The Metacognitive Awareness Inventory for Children (Jr. MAI)" were detected. Depending on each grade level students' maximum and minimum scores students' scores in each scale were separated into three groups (high-moderate-low) and this process was explained briefly as follows. For RFN student questionnaire this difference was 51 for 5^{th}, 69 for 6^{th}, 70 for 7^{th}, and 78 for 8^{th} graders. When these scores were divided into three groups, the cut points were 17 for 5^{th}, 23 for 6^{th}, 34 for 7^{th}, and 26 for 8^{th} graders. Moreover, students' scores from Jr. MAI Form A (administered to 5^{th} graders) and form B (administered to 6^{th}, 7^{th}, 8^{th} graders) were divided into three groups as well. The difference between the maximum and minimum score was 20 for 5^{th}, 54 for 6^{th}, 44 for 7^{th}, and 48 for 8^{th} graders. Thus, intervals were set as 7 for 5^{th}, 18 for 6^{th}, 15 for 7^{th}, and 16 for 8^{th} graders. This similar process in which score distribution and cut points were investigated for determining high, moderate, and low-level students were utilized in previous studies of RFN as well (e.g., Akgun & Kaya, 2020).

The reason of determining the high-moderate-low-level students for getting a homogenous sample for the interview process and reflecting representative sample for relating higher to lower profiles of RFN understanding and metacognitive awareness. Table 1 illustrates this sampling and corresponding number of students in this level range. For instance, the total number of students in 5^{th} graders is 180. Among these students one student corresponding to low level at both scales was selected. Similarly, among 180 5^{th} graders, eight students correspond to a moderate level at both scales, and one student was selected. Thus, one student from every grade level who place at low, moderate, or high was randomly selected. Three students from each grade level and in total 12 students were sampled for the interviews.

Table 1 Students' grade level and corresponding number of different level students in both RFN student questionnaire and the Metacognitive Awareness Inventory for Children instruments

Grade levels	RFN understanding level	Metacognitive awareness level	Number of students (n)	Total (N)
5th grade	Low	Low	1	180
	Moderate	Moderate	8	
	High	High	51	
6th grade	Low	Low	4	167
	Moderate	Moderate	36	
	High	High	39	
7th grade	Low	Low	3	170
	Moderate	Moderate	66	
	High	High	32	
8th grade	Low	Low	3	184
	Moderate	Moderate	79	
	High	High	27	
Total				701

3.3 Quantitative Instruments

One of the quantitative instruments of the current study is "RFN Student Questionnaire" (Cilekrenkli, 2019) that has been used to measure middle school students' RFN understanding. The original "RFN Questionnaire" has been created by Kaya et al. (2019) to assess teachers' RFN understanding. Cilekrenkli (2019) adapted this questionnaire for appropriate measurement to children's level with aiming to assess middle school students' (from 5th, 6th, 7th, and 8th grade) RFN understanding. The original language of the questionnaire is Turkish, and this version is delivered to participants.

A 37-item 5-point Likert scale "RFN Student Questionnaire" (Cilekrenkli, 2019) covers all categories of science holistically with both positive and negative items. The number of item distributions for these categories and sample items were provided in Table 2. From Table 2, it can pertain that distribution of the items is nearly equal except the social institutional system category which contains more questions due to the broad number of subcategories of this category. Moreover, sample items can be seen from the table as well. For instance, "scientists should respect the environment" is one of the questions that belong to the socio-institutional system category, and students are expected to rate items from 1 to 5 options (strongly disagree, disagree, neutral, agree, and strongly agree).

For content validity of the scale, Cilekrenkli (2019) consulted experts' opinions and managed pedagogical and linguistic adaptations. For reliability of the test, she found Cronbach alpha (α) value as .731 with fitting reliable range value (Pallant, 2010). In the current study, this reliability analysis was carried out ad found as 0.706.

Another quantitative data source is the "Metacognitive Awareness Inventory for Children" (Jr. MAI) (Karakelle & Sarac, 2007). It includes two versions (form A and form B) and measures students' metacognitive awareness levels. Jr. MAI version A measures 3rd, 4th, and 5th grade students' metacognitive awareness level while version B is for 6th, 7th, 8th, and 9th grade students. The inventories are based on Brown's (1987) framework of metacognition and the original scale "Metacognitive Awareness Inventory for Children" (Jr. MAI) constructed by Sperling et al. (2002). Karakelle and Sarac (2007) adapted these

Table 2 The categories, sample items, item distribution, and percentage correspondence of categories of RFN Student Questionnaire. Adapted from: (Cilekrenkli, 2019, p 50)

RFN categories	Sample items	Number of items	Percentage
Aims and values (AV)	Scientists should change their minds when they realize that their ideas are not supported by evidence.	4	10.8%
Scientific practices (SP)	All branches of science use observations.	8	21.6%
Methods and methodological rules (M)	Scientists have to use different methods to produce enough evidence so that they can solve problems.	4	10.8%
Scientific knowledge (SK)	Theories, laws, and models work together to produce scientific knowledge.	7	18.9%
Socio-institutional system (SI)	Scientists should respect the environment.	14	37.8%
Total		37	100%

versions to Turkish with establishing reliability and validity process. In the current study, these Turkish versions (Karakelle & Sarac, 2007) were administered, and while Jr. MAI form A was administered to 5th form B was applied to 6th, 7th, and 8th graders. For form A, the internal consistency value was found as .76 while for form B it is .82. After item-total correlation and factor analysis, they concluded that the adapted scale has reliable and valid measurement. In the current study, as a result of the reliability analysis for Jr. MAI A & B inventories, the Cronbach alpha values have been found as .83 and .80 respectively.

Jr. MAI form A contains 12 questions (maximum score is 36 and 12 for minimum). Jr. MAI form B contains 18 questions (maximum score is 18 and 90 for minimum) in addition to the same 12 questions that Jr. MAI A contains. Moreover, due to these score differences in Jr. MAI forms A and B and since form A was administered to 5th graders only, the current study defines the middle school student groups as 6th, 7th, and 8th graders. According to the participants' total scores from both "RFN Student Questionnaire" and the "Metacognitive Awareness Inventory for Children" 12 students (3 students from each grade level) were interviewed for the qualitative part. For the participants' selection, students who correspond to high/moderate/low level (in both RFN and metacognitive awareness scales) and different grade levels (5th, 6th, 7th, 8th grade) students were considered which were detailed at participant selection part.

3.4 Interviews

The interview data consolidated the quantitative data in terms of examination of students' RFN understanding, its categories, and metacognitive awareness. The interviews were consisting of two succeeding parts. At first, RFN-based interviews in which the focus is on getting students' further and detailed ideas for each category of science were conducted. The RFN-based questions including all RFN categories were adapted from previous studies and expert opinions were taken for validity of interview questions. Some sample interview questions were "What do scientific practices mean to you?", "What do you know about scientific knowledge?".

As the second part of the interviews, metacognitive awareness questions were directed to students to interpret their metacognitive actions, skills, or behaviors. Students' awareness of their learning, thinking process, and actions tried to be examined from their answers. Students' ability and capacity to express their metacognitive actions and processes showed their metacognitive awareness (Georghiades, 2004). During interviews, students were required to imagine and remember specific situations, report their behaviors while handling problems, what they do, and think in certain moments such as learning science. In this way, the qualitative data source allowed authors to delve deeply into the concept (Denzin & Lincoln, 2005). The sample questions were "How do you understand whether you learned the topic or not?" and "What kind of strategies do you use while studying or trying to learn a new topic?". These two successive interviews including 27 questions (see Appendix) were held in Turkish and lasted 1 h on average via an online platform. All interviews were audio-recorded with the permission of both students and their parents.

3.5 Data Collection and Analysis

The study was carried out in the 2020–2021 academic term in online classes. Students were able to reach surveys through links that were provided. The reason for sharing links at online classes is for ensuring the attendance of students to the survey so that they were able to raise their questions during implementation. Interviews, on the other hand, were conducted on the online platform.

As quantitative data analysis, Pearson product-moment was utilized to investigate the relationship between two constructs. The SPSS software application was used to analyze the data acquired from the "RFN Student Questionnaire" and "Jr. MAI" (forms A and B). After satisfying the assumptions, the Pearson product-moment test was performed for all middle school students and each grade level separately as well. In qualitative data analysis, thematic analysis (Braun & Clarke, 2006) was followed with the following six steps (familiarization, coding, generating, reviewing, and defining themes and reporting) to detect whether students use metacognitive strategies or show these skills while explaining science and its categories. After getting familiarized with data, the initial codes and themes for each category of science were formed.

For examining the relationship between these constructs, low, moderate, and high-level students' explanations in two interviews were compared. Whether a student who has low-moderate-high RFN level was providing the explanation in accordance with his/her level (low-moderate-high) in metacognitive awareness was examined. This process has been achieved in following way. First of all, each level students' answers in RFN were examined and coded for each category. Afterwards, overall interpretation about students' RFN understanding with considering students' other examples, detailed answers and their ability to make connections among different categories of RFN. Then, same student' answers in MA was examined and coded. For this part, researchers take into consideration what kind of metacognitive activities students were using, whether they aware in their actions or learning process and what they do and think in certain situations. For instance, the 8th grade high-RFN level student said that "*making lots of research is important for me to understand science..... For understanding this topic, I studied hard. But I have to make research not only for learning topics but also knowing more. The things that we learn is not all the science. Science is more than what we learn at lessons."* In this portion of excerpt, student' awareness of importance of learning science was coded. Then, compatibleness of these answers was constantly compared with another interview questions. After this process, coherence and alignment of these two interview results were provided at our result section.

Furthermore, the existence of metacognitive clues in students' RFN expressions, such as the utilization of planning, monitoring, and evaluation strategies, were also examined. The student from a high-RFN understanding level may utilize or prefer some metacognitive activities while trying to understand science or its categories. Therefore, the (non)existence of these strategies and students' expressions that shows their metacognitive awareness were examined. For instance, a 5th grade student expressed, *"….we observed the stars, moon and the phases of moon over one month. I see the crescent, full moon and each phases of moon with observing over one month and took notes....... I was thinking why we see moon in different shapes and what has been causing this to happen..... Before learning this at class, I had reinforced the topic, and this provide benefit for me to learn the phases of moon easily. For instance, I know the name of the phases and the time interval between them since I have already observed it*." Students cognitive-epistemic processes such as awareness in learning with practicing, use of techniques such as questioning, and her regulatory actions were coded. Moreover, the student was aware of epistemic-cognitive role of scientific practices. Similarly, same student' other answers were compared with metacognitive awareness–related questions. Students' verbal expressions on their actions, ideas about RFN, and their ability to express their mental process helped us to connect these two constructs. At the end of the interviews [RFN] and [MAI] (metacognitive awareness interview), brackets and low (*L*), moderate (*M*), and high (*H*) level students' symbols were used for representing these constructs.

In this process, the consent forms, anonymity, and confidentiality issues were considered, and all participants gave their informed consent before attending the study. The ethics committee from the Ministry of National Education of Turkey approved the current study with confirming recognized standards of ethics. Interrater reliability, in which two independent researchers codes the same interviews separately, was used to ensure the reliability of the interviews. The agreement rate was 91.5% and 82% for RFN and metacognitive awareness respectively.

4 Results

The results section presents the quantitative and qualitative results in a consecutive manner for representing the scope of the relationship between students' RFN understanding and metacognitive awareness. The first section describes quantitative results including the Pearson correlation and descriptive analysis results. The second section presents the qualitative results. We related our major findings by addressing the research questions in each section.

4.1 The Quantitative Results

Pearson correlation test was conducted for the total sample group and each grade level group of students. The results of intercorrelations and descriptive results in the total group and each grade level (5^{th}, 6^{th}, 7^{th}, and 8^{th}) students were presented in Table 3. The results show moderate mean score values for two variables. The RFN understanding scores are quite similar among each grade level which range between 133.10–136.81 (out of 185). On the other hand, students' mean scores in metacognitive awareness are 30.73 (out of 36) for 5^{th} grade students while this score was 72.03 (out of 90) for middle schoolers as a whole.

Our first major finding addresses the first research question of "Is there a statistically significant relationship between middle school students' RFN understanding and their metacognitive awareness?" Table 3 shows that there was a significant positive relationship

Table 3 Pearson correlation, mean, and standard deviation of middle and each grade level students' RFN understanding and metacognitive awareness

Grade level		*M*	*SD*	1	2
5^{th} grade	1. RFN understanding	133.89	10.73	-	.292**
	2. Metacognitive awareness	30.73	3.277		-
6^{th} grade	1. RFN understanding	133.10	12.91	-	.317**
	2. Metacognitive awareness	71.52	10.776		-
7^{th} grade	1. RFN understanding	136.81	12.13	-	.332**
	2. Metacognitive awareness	71.94	8.665		-
8^{th} grade	1. RFN understanding	135.80	11.95	-	.347**
	2. Metacognitive awareness	72.59	9.061		-
Middle schoolers (6^{th}, 7^{th}, and 8^{th})	1. RFN understanding	135.26	12.399	-	.331**
	2. Metacognitive awareness	72.03	9.517	-	-

**$p < .001$ (2-tailed)

between middle school students' RFN understanding and their metacognitive awareness (r (521) = .33, p< .01). The degree of the relationship is moderate level and in a positive way. Thus, a statistically significant relationship exists among 6th, 7th, and 8th grade level students' RFN understanding and their metacognitive awareness.

When each grade level students were considered, this relationship is still evident. Table 3 shows that there is a statistically significant relationship among 5th (r (180) = .29, p< .01), 6th (r (167) = .31 p< .01), 7th (r (170) = .33 p< .01), and 8th grade (r (184) = .34 p< .01) students' RFN understanding and their metacognitive awareness. Except 5th grade level students, the degree of relationship is moderate for each grade level and middle schoolers.

To sum up, the quantitative results show that the students who had high RFN understanding scores also had high metacognitive awareness scores on the Jr. MAI scale. Similarly, the students who had low RFN understanding scores also had low metacognitive awareness scores. This relationship was also evident among each grade level student (5th, 6th, 7th, and 8th) separately.

4.2 The Qualitative Results

This section reports the qualitative results that come from students' interviews. The consistency and compatibility of high, moderate, low-level students' detailed expressions about RFN and metacognitive awareness were examined case by case and reported with sample quotations. The results of the research question that is "How does the relationship between students' understanding of RFN and their metacognitive awareness differ among 5th, 6th, 7^{th,} and 8th graders?" has been addressed in this section.

As a result of thematic analysis, emerging themes for RFN were aims and values, scientific practices, method and methodological rules, scientific knowledge, and social institutional system (Erduran & Dagher, 2014). Some codes are serving to humanity, observation, experimentation, diverse methods, having presuppositions, theories-laws-models, respect for the environment, intellectual honesty, attending conferences, the relationship government and science, and financing studies. For metacognitive awareness, the themes were declarative, procedural and conditional knowledge, planning, monitoring, and evaluation (Schraw & Dennison, 1994). Some codes were knowledge about one's skills, use of learning strategies, strategic selection of techniques, reflective thinking and activities, asking questions, goal setting, sub goals, checking comprehension and task performance, and assessing the performance.

The comparison of each low, moderate, and high-level student's expressions was followed through each grade level student. For clear expression, sample quotations from RFN and metacognitive awareness–related interviews were provided. It was considered whether students who use metacognitive skills for their learning process or in their actions were able to explain the science and its categories. If students who use metacognitive skills and actions have high-RFN and metacognitive awareness levels, and if most students' answers were aligned in this way, there could be a possibility of a relationship between these concepts.

As a first point, when students' answers for science and its categories were investigated, it has been seen that some metacognitive clues exist at high- and some moderate-level students' expressions. For example, 5th grade high-level student explains one of the scientific practices. She exemplified this process with her experience in making an observation.

Her actions include metacognitive actions such as questioning, monitoring strategies, and awareness in the learning process.

> *Student: Scientists can make observations in their studies. They can make research and observe what is happening.*
>
> *Researcher: Can you explain more about what you mean?*
>
> *Student: For instance, my uncle had a telescope. We observed the stars, moon, and phases of the moon over one month. I see the crescent, full moon, and each phase of the moon with observing over one month. Every week moon transitioned new phase and I took notes. While we were observing, I was thinking about why we see the moon in different shapes and what has been causing this to happen. I asked my teacher. Before learning this unit in the class, I had reinforced the topic, and this provided benefit for me to learn the phases of the moon easily. For instance, I know the name of the phases and the time interval between them since I have already observed them.* [5th-H-RFN]

The student clearly explains how she learned this unit, which strategies are effective for her while learning phases of the moon and this comes from her observation experience. She was aware that this experience eased her learning process. Moreover, her responses to metacognitive awareness–related questions were aligned in terms of using these metacognitive skills.

> *I sometimes think in my head. For instance, when I come up with a hard question, I start to think about how I can formulate this and what I will going to say. I ask these kinds of questions. I can say that I am a person who always asks questions and think in this way.* [5th-H-MAI]

The student expresses her internal thinking process and was using some metacognitive strategies such as self-questioning techniques. She was aware of these processes and her notions were in alignment in terms of utilization of strategies and awareness of her learning process while making an observation.

For the 7th grade level, when the high-level student was asked about the scientific method, the student explained the presuppositions of scientists and linked this with scientists' cognitive process and differences in others' thinking way. The student was able to explain testing scientific presuppositions and viewed this as one of the scientific methods that scientists use.

> *Student: Scientists' presuppositions can be verified as a result of their studies. So, they can come along with the same or different results at the end of their studies. But their presuppositions may not be proved since their assumptions cannot be aligned with the results. Every scientist's way of thinking and methods cannot be the same. For instance, I can approach context differently, and my assumptions can be different normally. But sometimes they can satisfy their expectations and reach conclusions so their previous thoughts and assumptions can be close to reality as well. It depends on the people's thinking way and knowing. They need to be careful about thoughts with knowing and being conscious of what they do. In sum, presuppositions can be satisfied or dissatisfied.* [7th-H-RFN]

It can be said that the student can link the metacognitive thinking process and assumption checks in scientific studies. He was mentioning differences in scientists' thinking process which can be an effective factor while constructing presuppositions and was aware of others' thinking way and outcomes of their thinking. When his answers to metacognitive awareness–related questions were examined, the student mentioned his learning strategies and metacognitive actions such as questioning, monitoring, and he was trying to ensure an effective learning process. For instance,

> *I can understand whether I learn the topic or not...umm... I ask questions to myself and try to solve problems by myself. For instance, I try to summarize the things that I learned from someone. If I can't manage this, I thought that I couldn't understand the topic and needed to feel for studying hard.* [7th-H-MAI]

This student's metacognitive awareness interview also showed his strategy and articulation of this metacognitive process such as checking and monitoring his actions, use of learning strategies, and ensuring the learning process. Thus, these sophisticated responses were evident in each high-level student's explanations in both RFN and metacognitive awareness. On the other hand, in other grade levels (6th and 8th) high-level students' responses in two interviews were parallel in terms of complexity and similar expressions. The students who express science and its categories in a systematic and sophisticated way, we were also able to express their metacognitive actions and thinking process in this way.

Furthermore, the moderate-level students' ideas in science and its categories were including some notions related to metacognitive awareness. For instance,

> *Everyone has different subjective judgment. Everyone has different thoughts and scientific studies, and these can be affected because of differences in personal characteristics. So, scientists with different characteristics can have different thoughts even on the same issue. This happens in my life as well. I could defend different thoughts as opposed to my friends' ideas. Different kinds of scientists can have different thoughts. So personal characteristics affect scientific works.* [8th-M-RFN]

This moderate-level student was also aware of differences in others and their own thinking process. Then, she related this difference with the effect of personal thoughts on scientific studies. This student was also aware that scientific studies are subject to rational criteria which she mentioned in her notions. This means that the evaluation criteria of scientific studies should not be under the scrutiny of personal factors. Parallel to this, the student was expressing her learning process with having awareness of her thinking process. The other moderate-level students (except 5th and 6th graders) were utilizing metacognitive clues such as self-questioning, monitoring while expressing science and its categories.

When the consistency of low-level students' expressions was examined, students were explaining science and its categories naïvely. Some students were mistakenly believing the myth of one scientific method, scientific knowledge as the static and unchanging, and scientific laws as governmental laws. For instance,

> *As a method, umm, they can use microscopes for their investigations. They can use a magnifying glass, so something like cottony. So umm... DNA thing, you put it to the capsule and investigate it. They put it in the box and extract it.*
>
> *Researcher: So you think that these are scientific methods that scientists use. Do you think that do all scientists use the same methods?*
> *Student: I think that they all use the same methods. I mean they make common science. So, if they use different techniques, some big problems could have appeared.*
> [6th-L-RFN]

The student believes the one scientific method myth naïvely without viewing the diversity of scientific methods in science. Moreover, material practices of science such as the use of tools and calibration of scientific instruments were viewed as methods of science. These similar naïve ideas were evident among most low-RFN level students. On the other hand, the same student's expressions in metacognitive awareness interviews were also parallel in terms of the limitedness of answers. For example, when the low-level 6^th^ grade student was asked about his strategy selection and management of his learning process, he stated that

> *I search on the Internet and books. I get support from them. My mom also helps me to learn. For example, she tells me what to study. We generally study together. She asks me questions. If I can answer them, she tells me that I learned it. And in this way, I learn. I do these kinds of things for learning science topics.* [6th-L- MAI]

This student stated that her mother takes decisions and directs his learning process. Rather than regulating and navigating his own cognitive process, the student needs to take external help for the articulation of his learning. When his other answers in metacognitive awareness (e.g., fail in goal setting, planning, and time management) were also considered, these all show this low-level student's limited capacity and low level of awareness of his learning and thinking process. In other grade levels, students (5th, 7th, and 8th graders) who have low-level RFN and metacognitive awareness were also ineffective in the use of metacognitive strategies such as monitoring the learning process, planning time and action, and self-testing of behaviors. To sum up, students with high-RFN levels who were able to explain science, and its categories were more metacognitively aware than students with low-RFN levels who were not. These parallel answers were also evident for moderate or low-level students and each grade level student as well. Thus, these all cases show us that these two concepts can be linked.

Moreover, each grade level student's expressions were reflected as well. In preceding results, low, moderate, and high-level students' expressions in both RFN and metacognitive awareness interviews were reported. However, students' expressions and complexity of answers through each grade level were varying with their grade level. Fifth graders were generally providing simple and less detailed expressions for RFN and metacognitive awareness interviews. For instance, 5th grade level students were only expressing observation as scientific practices. Their expressions of metacognitive actions were not detailed on which strategies they use, how they learn the science, and what other people thinking processes differ. Sixth graders, on the other hand, expressed many categories of science with diverse examples and described their metacognitive strategies with awareness of their knowledge of the cognition process. However, only high-level students' answers were in this way. Moderate-and-low levels students' expressions were still linked but the variability and depth of their notions were changing. Among 7th graders, both high- and moderate-level students were considering self-questioning and strategy selection for solving and understanding problems. The diversity of strategies that students practice, and their thinking process were more holistic, and they were able to detect and articulate their learning process in science. Eight grade students, on the other hand, were able to explain scientific laws and models relating to the development of scientific knowledge and their importance as one of the knowledge types in science. The students from low-moderate and high-level were able to realize their own learning strategies, when and how to use them, and aware of how they learn better.

To sum up, the qualitative results, while students with high metacognitive awareness levels tended to view science in a more comprehensive way, students with low metacognitive awareness levels were prone to view science and its categories in a more limited way. Students who utilize metacognitive strategies (e.g., evaluation, management) and knowledge about his/her learning process were able to view science and its categories (e.g., novelty of studies, diversity of scientific methods; the work of theories, laws, and models; intellectual honesty). However, students who lack those metacognitive strategies and awareness of/her learning process were limited in providing explanations (e.g., the one scientific method, inability to distinguish scientific practices from methods of science). This tendency was also evident among 5th, 6th, 7th, and 8th graders separately as well. Moreover, each grade level students' expressions were matching in terms of complexity and similar answers. When this context is interpreted with the quantitative results (the strength of the relationship was increasing as grade levels), it can be concluded that the qualitative result is parallel with the quantitative results. Thus, the convergence of quantitative and qualitative results shows the possible relationship between students' RFN understanding and their metacognitive awareness. Since most students' answers were consistent and aligned like this way, this could point to the possible relationship between these variables. Although it cannot be directly concluded that students' answers directly resulted from their metacognitive skills or actions, these were only indicators of a possibility of a relationship.

5 Discussion

This explanatory sequential mixed-method design study investigated the relationship between students' RFN understanding and their metacognitive awareness through quantitative and qualitative perspectives. The quantitative results indicated a significant positive relationship between these constructs. Furthermore, qualitative results indicate that the students who had high metacognitive awareness were able to explain RFN and its categories, while low-level students who had low-level metacognitive awareness were not able to explain RFN and its categories. The qualitative analysis results were consistent with the scores of RFN student questionnaire and Jr. MAI forms. Thus, both quantitative and qualitative data supported that students' RFN understanding and metacognitive awareness are related constructs. This means that students' awareness of their own thinking process and their use of metacognitive strategies are related to their understanding of science and its categories. This promises if students become metacognitively aware, they can understand and explain RFN in a more comprehensive and structured way. The possible reason for this result can be due to the nature of the complimentary (meta)cognitive dimensions of RFN. As authors (Erduran & Dagher, 2014) proposed, FRA has the potential to include metacognitive dimensions. Therefore, the results of this study support this argument and show this potential link between metacognitive awareness with RFN understanding. While thinking different branches of science students reflect and organize their thinking around these kinds of differences which demands metacognitive actions.

Furthermore, the findings also point out that the relationship between these constructs was evident among 5th grade level students as well although the degree of this relationship was considerably low. The reason for this can be due to students' development of metacognitive skills through an age that may interfere with students' metacognitive awareness level. This ongoing process has not been completed before the age of 11–12 (Veenman et al., 2004; Veenman, & Spaans, 2005). This developmental process can be logical for the low-level degree of relationship among 5th graders and the reason for the increase in strength of the relationship through grade levels.

In addition, the outcomes of this study were aligned with the previous studies on metacognition and NOS. A similar study (Gulsuyu, 2019) examined the relationship between students' NOS understanding and their metacognitive awareness that was based on a consensus view of NOS. The researcher found a significant positive relationship between these two constructs and the degree of correlation coefficient ($r= .306$, $p < .01$) was quite similar with our study ($r = .333$, $p< .01$). However, the qualitative dimension of this similar study was deficient compared to the current study. Particularly, the epistemic-cognitive and social components (e.g., ideas on the wheel) of RFN framework add critical value in terms of understanding and linking students' reflective thinking on science disciplines, critical judgment on the diversity of scientific methods, and evaluation of the knowledge that scientists produce. This interpretation from RFN framework also informs classroom practice in a way to develop students' understanding of epistemic-cognitive social components of science, its domain-specific general characteristics, viewing a holistic image of science with interrelating different categories of science.

Another study (Cetinkaya-Aydın & Cakıroglu, 2017) concentrated on preservice teachers' characteristics and their nature of science ideas including its association with metacognitive awareness. They concluded that there are significant differences among preservice teachers' scores who have informed/adequate and inadequate views in terms of the subcomponents of metacognitive awareness. In addition, the experimental studies (Abd-El-Khalick & Akerson, 2009; Baraz, 2012) acknowledge the effectiveness of metacognitive strategies on NOS education. The study (Abd-El-Khalick & Akerson, 2009) reported that utilization of metacognitive strategies increases preservice teachers' metacognitive awareness and their NOS understanding. Moreover, in the middle school science context, students get significant gains in the content knowledge and the nature of scientific knowledge as a result of the implementation of metacognitive prompts in NOS lessons (Peters & Kitsantas, 2010). Thus, these affirmative results also point to the possible relationship between these concepts which are parallel with the current study.

The current study points the importance of metacognitive actions in NOS education from RFN perspective. For instance, metacognitively aware students mentioned the importance of diversity of scientific methods with connecting the evaluation criteria of scientific studies, domain-specific characteristics of science, testing scientific presuppositions, and verification process. Some students were aware that making observation is one of scientific practices to understand scientific phenomena with criticizing the function of scientific practices. These epistemic-cognitive dimensions of RFN helped them to interpret and understand the scientific concepts which allowed them to think on their scientific thinking process. Making critical judgments, scientific norms, or subjecting scientific ideas to rational criteria, distinguishing personal characteristics while making science were indicators of students' awareness in social characterization of RFN. The study provides initial understanding about the place of students' awareness in reflective, critical, evaluative scientific thinking process in terms of holistic categorization of RFN. These metacognitively aware students' answers were leading some implications in RFN teaching. For instance, while students try to practice some scientific procedures such as making observations, collecting data, and presenting their findings, the teacher can help students to question their steps, reflect what they practiced, have them to discuss and reason the scientific knowledge, and evaluate scientific products of community. The use of both explicit and implicit metacognitive prompts has potential to unfold students' RFN ideas. These metacognitive actions may allow students to question their scientific ideas and paradigms; criticize the role work of theories, laws, and models (TLM); distinguish pseudoscience; and get aware of diversity of scientific methods, domain-specific characteristics of science, and social mechanism of science. In this way, students' RFN learning process will be promoted with having them to regulate and control their thinking process, and they will get aware of their scientific thinking process from epistemic-cognitive and social dimensions. Therefore, the introduction of metacognitive awareness context in RFN framework allows not only educators but also curriculum developers and teacher education programs for considering the metacognitive dimension while teaching or developing material for the nature of science education.

Paying closer attention to different level students who have low, moderate, or high-level RFN understanding and metacognitive awareness is critical for inclusion or development of low-level students' understanding. Teachers can have an idea about their students' RFN understanding level by observing or noticing their metacognitive awareness level. In addition to these contributions, limitations of the study need to be also considered. The variables that have been set for the study were the independent variable (students' metacognitive awareness) and the dependent variable (students' RFN understanding). However, as the nature of correlational studies, the extraneous variable(s) could have a place in this association. For instance, students' developmental process in metacognitive awareness of previous experiences in the nature of science could be extraneous factors that cannot be directly measured.

As concluding remarks, the overall study shows the relationship between students' RFN understanding and their metacognitive awareness. This related construct can be the focus of the further NOS studies in a way to use metacognitive strategies that will enhance students' RFN understanding. The introduction of these strategies may allow students to grasp different aspects of science and its categories. In terms of implications for classroom teaching and learning, since students who have a low level of metacognitive awareness are prone to have a low level of RFN understanding, the detection or observation of these students may help support teachers' classroom practices about NOS.

Appendix. Interview questions

Introduction

1. What do you think about science lessons? What are your responsibilities and duties for science lessons?

- What do you do in science lessons? What your teacher and you do in lessons?

2. What comes to your mind when I say science?

RFN-based questions

3. Who does science? What do you think on how they do scientific work?
4. Why do scientists conduct scientific studies? What are their purposes for conducting these scientific studies?

- What are values of science? (What are the values that scientists must follow?)

5. What does scientific practices mean to you? What kind of scientific practices do scientists have?

- What comes to your mind when I say observation? Have you ever had an opportunity to make observation in science lessons?
- Do you think that science or scientists are observations?
- What do you know about classification? Do scientists make classifications?
- What comes to your mind when I say experiment? What can be the purpose of making experiments in science?

6. What comes to your mind when I say scientific methods? For instance, you are scientist and have a research question. You want to examine celestial bodies or features of COVID 19 virus. Which scientific methods do these scientists use?

- Think of scientists who work in different branches of science. Can the methods that they use be same or different?
- Do scientists have presuppositions or expectations for the results of their studies? (If yes, can their suppositions contradict with their results? / their results can appear different from their expected results?)

7. What do you think about scientific knowledge? How do scientists reach scientific knowledge?

- What are the forms of scientific knowledge? (What is the meaning of theory and law?)
- What do you think about scientific model? Do scientists use scientific models? (If yes, what can be their aim for using scientific models? If no, why not?)
- Do you think that the scientific knowledge change? (If yes, how it can change and develops? If no, why?)

8. What scientists do when they discover new thing or reach important conclusion?
9. Do you think that scientists want to inform and share their results with people and other scientists? (If yes, what do they do ? Can you explain this process?)
10. What do you think that professional activities that scientists take?

- Have your ever heard the words like conferences and seminars? Do you think that there is a relationship between scientists and conferences/seminars? (If yes, what kind of relationship could be? / What could they do in these conferences?)

11. What are the things that scientists need to be careful while working together or their relationship with each other?
12. Do you think that does religion, gender or personal thoughts have effect on scientists' results of studies? If yes, how and in what way? If no, why?
13. Let's say that a scientist do a scientific work about environment. Another scientist study with animals. What are the rules or values that these scientists need to follow?

- Are scientists free in their work?

14. Do you think that governments affect scientists' work? How?

- What kind of relationship exists between science and politics?

15. Do you think that financial issues are related to science? Why?
16. Where do scientists perform their work?

Metacognitive awareness questions

17. Now I want you to imagine yourself while learning new topic in science. Let's say you are learning new topic and try to understand it. (After waiting half minutes) which thoughts pass through in your mind?

- Now I want you to describe your learning process in this science topic. Let's take an example of seasons and climate unit. What you have done to learn this topic and what did you do?

18. How do you understand whether you learned the topic or not?
19. What kind of strategies do you use while studying or trying to learn new topic?

- Why do you use these strategies? Is there a specific time for you to use these techniques?

20. What you generally do when you come up with important information while studying?
21. Do you put specific goals for learning? Can you give example for them?

- Do you ask yourself whether you reach or accomplished your aim?
- How do you check whether you reached your goal?

22. What are your cognitive strengthens and weakness?
23. Now I want you to think of your specific moment. You have just finished your exam. Can you imagine that moment? (After short moment) While solving problems and after the exam what you generally think?

- Do you generally evaluate your learning process?
- For instance, you had exam and after that do you predict your score?

24. What do you think on your thinking way? For example, you have hard question and trying to solve it. What do you think while doing this? Do you think alternative ways or ask questions to yourself while thinking and problem-solving? If yes, can you give example about last situation you did this?
25. Now, I want you to think of your special moment while studying again. Can you describe your internal speech, thoughts or things that you realized that moment?
26. How do you manage your time and time you devote for learning?

- Do you specifically set time intervals or goals for yourself? How do you manage this?

27. You have mentioned learning techniques before. How and when you use them?

- Is it easy for you to learn with online lessons?
- Can you learn on your own when needed?

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Declarations

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

Ethics Approval The approval from the ethical committee of the Ministry of National Education of Turkey and Bogazici University have been taken for the study.

References

Abd-El-Khalick, F. (2014). The evolving landscape is related to assessment of nature of science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research in science education* (Vol. 2, pp. 621–650). New York, NY: Routledge.

Abd-El-Khalick, F., & Akerson, V. (2009). The influence of metacognitive training on preservice elementary teachers' conceptions of nature of science. *International Journal of Science Education, 31*(16), 2161–2184.

Akbayrak, M., & Kaya, E. (2020). Fifth-grade students' understanding of social-institutional aspects of science. *International Journal of Science Education, 42*(11), 1834–1861.
Akben, N. (2018). Effects of the problem-posing approach on students' problem-solving skills and metacognitive awareness in science education. *Research in Science Education, 50*, 1–23.
Akerson, V., & Donnelly, L. A. (2008). Relationships among learner characteristics and preservice elementary teachers' views of nature of science. *Journal of Elementary Science Education, 20*(1), 45–58.
Akerson, V., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37*(4), 295–317.
Akerson, V., Morrison, J., & Roth McDuffie, A. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching, 43*(2), 194–213.
Akgun, S., & Kaya, E. (2020). How Do University Students Perceive the Nature of Science? *Science & Education, 29*(2), 299–330.
Allchin, D. (1999). Values in science. *Science & Education, 8*(1), 1–12.
Allchin, D. (2011). Evaluating knowledge of (whole) science. *Science Education, 95*(3), 518–542.
Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature of science: Integrating student inquiry, historical cases, and contemporary cases in classroom practice. *Science Education, 98*(3), 461–486.
American Association for the Advancement of Science [AAAS]. (1990). *Science for all Americans*. New York, NY: Oxford University Press.
Annevirta, T., & Vaurus, M. (2006). Developmental changes of metacognitive skill in elementary school students. *The Journal of Experimental Education, 74*, 197–225.
Baraz, A. (2012). *The effect of using metacognitive strategies embedded in explicit- reflective nature of science instruction on the development of pre-service science teachers' understanding of nature of science* (Publication No. 321116). [Master's thesis, Middle East Technical University]. National Thesis Center.
Beeth, M. E., & Hewson, P. W. (1999). Learning goals in exemplary science teacher's practice: Cognitive and social factors in teaching for conceptual change. *Science Education, 83*(6), 738–760.
Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology 3*(2), 77–101.
Brown, A. L. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 65–116). Lawrence Erlbaum Associates.
Cetinkaya-Aydın, G., & Cakıroglu, J. (2017). Learner characteristics and understanding nature of science. *Science & Education, 26*(7), 919–951.
Cheung, K. K. C. (2020). Exploring the inclusion of nature of science in biology curriculum and high-stakes assessments in Hong Kong. *Science & Education, 29*(3), 491–512.
Chiu, M. H., & Duit, R. (2011). Globalization: Science education from an international perspective. *Journal of Research in Science Teaching, 48*(6), 553–566.
Choi, K., Lee, H., Shin, N., Kim, S. W., & Krajcik, J. (2011). Re-conceptualization of scientific literacy in South Korea for the 21st century. *Journal of Research in Science Teaching, 48*(6), 670–697.
Cilekrenkli, A. (2019). *Teaching reconceptualised family resemblance approach to nature of science in lower secondary classrooms* (Publication No. 603292) [Master's thesis, Bogazici University]. National Thesis Center.
Cilekrenkli, A., & Kaya, E. (2022). *Learning science in context: Integrating a holistic approach to nature of science in the lower secondary classroom*. Science & Education. https://doi.org/10.1007/s11191-022-00336-0.
Cofré, H., Núñez, P., Santibáñez, D., Pavez, J. M., Valencia, M., & Vergara, C. (2019). A critical review of students' and teachers' understandings of nature of science. *Science & Education, 28*, 205–248.
Crawford, B. A. (2014). From inquiry to scientific practices in the science classroom. In N. Lederman & S. Abell (Eds.), *Handbook of research on science education* (Vol. II). Routledge.
Crawford, B. A., & Capps, D. K. (2018). Teacher cognition of engaging children in scientific practices. In Y. Judy Dori, Z. M. Mevarech, & D. R. Baker (Eds.), *Cognition, metacognition, and culture in STEM education*. Springer.
Creswell, J. W. (2012). *Research design: Planning, conducting, and evaluating quantitative and qualitative research*. Pearson.
Cullinane, A. (2018). *Incorporating nature of science in initial science teacher education.* (Unpublished doctoral dissertation). University of Limerick, Ireland.
Denzin. N. K., & Lincoln, Y. S. (2005). The discipline and practice of qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (3rd ed., pp. 1–32). Thousand Oaks, CA: Sage.
Dori, Y. J., Mevarech, Z., & Baker, D. (2018). *Cognition, metacognition, and culture in STEM education*. Springer.

Duschl, R. A. (1994). Research on the history and philosophy of science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 443–465). Macmillan.

Erduran, S., & Dagher, Z. (2014). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories*. Springer.

Erduran, S., Kaya, E., Cilekrenkli, A., Akgun, S., & Aksoz, B. (2021). Perceptions of nature of science emerging in group discussions: A comparative account of pre-service teachers from Turkey and England. *International Journal of Science and Mathematics Education, 19*(7), 1375–1396.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In L. B. Resnick (Eds.), *The nature of intelligence* (pp. 231–235). Lawrence Erlbaum.

Georghiades, P. (2004). From the general to the situated: Three decades of metacognition. *International Journal of Science Education, 26*(3), 365–383.

Grotzer, T., & Mittlefehldt, S. (2012). The role of metacognition in children's understanding and transfer of explanatory structures in science. In A. Zohar & Y. J. Dori (Eds.), *Metacognition in science education: Trends in current research* (pp. 79–99). Springer.

Gulsuyu, F. (2019). *Ortaokul Öğrencilerinin Üst Bilişsel Farkındalık Düzeyleri ile Bilimin Doğası Anlayışları Arasındaki İlişkinin İncelenmesi* (Publication No. 441101) [Master's thesis, Adıyaman University]. National Thesis Center.

Guskey, T. R. (2007). Multiple sources of evidence: An analysis of stakeholders' perceptions of various indicators of student learning. *Educational Measurement: Issues and Practice, 26*(1), 19–27.

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

Hofstein, A., Kipnis, M., & Kind, P. (2008). Learning in and from science laboratories: Enhancing students' meta-cognition and argumentation skills. In C. L. Petroselli (Ed.), *Science education issues and developments* (pp. 59–94). Nova.

Hsu, Y. S., & Lin, S. S. (2017). Prompting students to make socio scientific decisions: Embedding metacognitive guidance in an e-learning environment. *International Journal of Science Education, 39*(7), 964–979.

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

Irzik, G., & Nola, R. (2014). New directions for nature of science research. In M. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 999–1021). Springer.

Jimenez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education, 84*(6), 757–792.

Karakelle, S., & Sarac, S. (2007). Çocuklar için üst bilişsel farkındalık ölçeği (ÜBFÖ-Ç) A ve B formları: Geçerlik ve güvenirlik çalışması. *Türk Psikoloji Yazıları, 10*(20), 87–103.

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

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

Khishfe, R. (2008). The development of seventh graders' views of nature of science. *Journal of Research in Science Teaching, 45*(4), 470–496.

Kuhn, T. S. (1977). *The essential tension.* University of Chicago Press.

Kuhn, D., Zillmer, N., Crowell, A., & Zavala, J. (2013). Developing norms of argumentation: Metacognitive, epistemological, and social dimensions of developing argumentive competence. *Cognition and Instruction, 31*, 456–496.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–879). Lawrence Erlbaum.

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

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

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

Nehring, A. (2020). Naïve and informed views on the nature of scientific inquiry in large-scale assessments: Two sides of the same coin or different currencies? *Journal of Research in Science Teaching, 57*(4), 510–535.

NGSS Lead States. (2013). *The next generation science standards*. National Academy Press.

Okan, B., & Kaya, E. (2022). Exploring the Inclusion of Nature of Science in Turkish Middle School Science Textbooks. *Science & Education*. https://doi.org/10.1007/s11191-022-00371-x.

Olson, H. A. (1998). Mapping beyond Dewey's boundaries: Constructing classificatory spaces for marginalized knowledge domains. *Library Trends, 47*(2), 233–254.

Pallant, J. (2010). *SPSS survival manual: A step by step guide to data analysis using the SPSS program (4th ed.).* McGraw-Hill Company.

Peters, E., & Kitsantas, A. (2010). The effect of nature of science metacognitive prompts on science students' content and nature of science knowledge, metacognition, and self- regulatory efficacy. *School Science and Mathematics, 110*(8), 382–396.

Peters-Burton, E. E., & Burton, S. R. (2020). The use of metacognitive prompts to foster nature of science learning. In W. F. McComas (Ed.), *Nature of science in science instruction* (pp. 179–197). Springer International Publishing.

Polit, D. F., & Beck, C. T. (2012) *Nursing research: Generating and assessing evidence for nursing practice* (9th ed.). Wolters Kluwer.

Sarıbas, D., Mugaloglu, E. Z., & Bayram, H. (2013). Creating metacognitive awareness in the lab: Outcomes for preservice science teachers. *Eurasia Journal of Mathematics, Science & Technology Education, 9*(1), 83–88.

Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology, 19*(4), 460–475.

Schraw, G., Olafson, L., Weibel, M., & Sewing, D. (2012). Metacognitive knowledge and field-based science learning in an outdoor environmental education program. In A. Zohar & Y. J. Dori (Eds.), *Metacognition in science education* (pp. 57–77). Springer.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*(4), 610–645.

Sperling, R. A., Howard, B. C., Miller, L. A., & Murphy, C. (2002). Measures of children's knowledge and regulation of cognition. *Contemporary Educational Psychology, 27*(1), 51–79.

Swanson, H. L. (1990). Influence of metacognitive knowledge and aptitude on problem solving. *Journal of Educational Psychology, 82*(2), 306.

Tao, P. K. (2003). Eliciting and developing junior secondary students' understanding of the nature of science through a peer collaboration instruction in science stories. *International Journal of Science Education, 25*(2), 147–171.

Thomas, G. P. (2011). Metacognition in science education: Past, present and future considerations. In B.J. Fraser, K.G. Tobin, & C.J. McRobbie (Eds.), *Second international handbook of science education* (pp. 131–144). Dordrecht: Springer.

Thomas, G. P., & McRobbie, C. J. (2001). Using a metaphor for learning to improve students' meta- cognition in the chemistry classroom. *Journal of Research in Science Teaching, 38*(2), 222–259.

Veenman, M. V. J., & Spaans, M. A. (2005). Relation between intellectual and metacognitive skills: Age and task differences. *Learning and Individual Differences, 15*, 159–176.

Veenman, M. V. J., Wilhelm, P., & Beishuizen, J. J. (2004). The relation between intellectual and metacognitive skills from a developmental perspective. *Learning and Instruction, 14*, 89–109.

Wilson, E. O. (1998). *Consilience: The unity of knowledge*. Alfred A. Knopf.

Wittgenstein, L. (1958). *Philosophical investigations.* Blackwell.

Yang, S., Park, W., & Song, J. (2020). Representations of nature of science in new Korean science textbooks: The case of 'scientific inquiry and experimentation'. In T. W. Teo, A.V. Tan & Y. S. Ong. (Eds). *Science Education in the 21st Century* (pp. 19-35). Springer.

Yeh, Y. F., Erduran, S., & Hsu, Y. S. (2019). Investigating coherence about nature of science in science curriculum documents. *Science & Education, 28*(3), 291–310.

Young, A., & Fry, J. D. (2008). Metacognitive awareness and academic achievement in college students. *Journal of the Scholarship of Teaching and Learning, 8*(2), 1–10.

Zohar, A. (2006). The nature and development of teachers' metastrategic knowledge in the context of teaching higher order thinking. *The Journal of the Learning Sciences, 15*, 331–377.

Zohar, A., & Dori, Y. J. (2012). *Metacognition in science education: Trends in current research*. Springer.