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# Middle School Graduates' Understandings of Scientific Inquiry and Its Relation to Academic Achievement

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## Abstract

There are conflicting reports not only on the effect of scientific inquiry on academic achievement but also insufficient evidence on the relationship between understanding the nature of scientific inquiry and academic achievement; more generalizable studies are needed. The purpose of this large sampled study was to investigate the middle school graduates' understandings of scientific inquiry (SI) and the relationship between students' understandings of SI and academic achievement. The sample of the study ($X = 3067$) was selected by purposeful and layered-sampling techniques among ninth grade students studying at high schools with different orientations in Istanbul. Descriptive and inferential statistical approaches were used in the data analysis procedure. The students' academic achievement was operationally defined as the scores they received in the High School Entrance Exam (HEE). Views about scientific inquiry scale was applied to determine the participants' understandings about scientific inquiry. The data were collected in the first 2 weeks of the first semester of high school in accordance with the purpose of the study. The results of the study revealed that middle school graduates generally do not have adequate understandings of SI. Furthermore, according to the findings except for the "conclusion data conformity" aspect, there are statistically significant correlations between students' academic achievement and understandings in all aspects of SI.

**Keywords** Academic achievement · Middle school students · Scientific inquiry · VASI

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## Introduction

In the last century, science has increasingly become an integral part of our culture and social life. It is difficult to talk about human values, political and economic issues, or educational goals today, without considering science's involvement (Aikenhead, 2006; Roberts, 2007). As a result, it is now widely accepted that, especially in the wake of the COVID-19 pandemic, democratic societies in the twenty-first century will require science-literate citizens who understand how science works and an environment allowing them to engage in critical dialogue about the political, social, personal, and moral dilemmas posed by science and technology (Irez, 2009; Osborne et al., 2003). Many countries consider it vital to foster a community of scientifically literate citizens, and it is recognized as one of the primary purposes of science education (Roberts & Bybee, 2014). The National Research Council declared that "inquiry is central to science learning" (NRC, 1996, p. 2) to achieve a vision of a scientifically literate citizenry. Scientific inquiry is simply the systematic research activities carried out to understand and explain the world by scientists (NRC, 2000). John Dewey stated more than a century ago, in 1909, that performing science is not just about acquiring content knowledge, but also about learning and experiencing a process (NRC, 2000; Simon et al., 2006). During middle of the twentieth century, this approach became more prominent (NRC, 2000). General science process skills together with the conventional content of science, critical thinking, and creativity for development of scientific knowledge are collectively termed as scientific inquiry (SI) (Lederman & Lederman, 2010). In an inquiry-based classroom, on the other hand, students participate in experiments and investigations that require them to formulate questions and hypotheses, gather and evaluate data, draw conclusions, and test them (Dogan et al., 2017; Tas et al., 2019). The process of SI has been considered one of the important aspects of learning and teaching since it indicates how valid scientific knowledge is constructed. In various educational settings, inquiry is therefore considered as a method for developing understanding as well as a content standard for science learning (Concannon et al., 2020; Schallert et al., 2022). SI-based education is considered to be an inductive teaching strategy which is mainly based on constructivist theory (Prince & Felder, 2006). In particular, it is assumed that the learner develops her/his understanding during the process of learning (Cairns, 2019). This approach of teaching is mostly approved by science educators who consider it a useful model for teaching (Anderson, 2002; Chinn & Malhotra, 2002).

### Cognitive Domains of Inquiry Require Different Perspectives in Teaching

Since the post-Kuhnian philosophy of science has changed the understanding of the nature of scientific knowledge, SI in science classrooms has taken on various definitions over time (Abd-El-Khalick & Lederman, 2000). Inquiry teaching strategy ensures that the science content is not only delivered to students in an interactive style, but also encourages students to make their own contributions in the working

process and eventually learn experimentally (Cairns, 2019; Huang et al., 2021). Furtak et al. (2012) identified four cognitive domains of inquiry-based teaching, namely, procedural, epistemic, social, and conceptual. While the procedural domain has to do with imitating the scientific inquiry process by including students in a process where they generate questions and hypotheses, analyze data, and then interpret them, epistemic domain focuses on how scientific knowledge is developed and evaluated. The social domain emphasizes science as a collaborative activity including discussions and the communicating ideas (Abd-El-Khalick, 2012; Kock et al., 2015). Finally, the conceptual domain is concentrated on the content knowledge of the students (Dogan et al., 2017). If science classes are primarily focus on procedural design, students may not understand *what science is* and *how it works* (Lederman et al., 2014).

Inquiry-based activities requires not only replicating a set of pre-existing procedures, but also comprehending the foundations of nature of scientific knowledge, which clearly depicts the fundamentals of SI. Therefore, it is a common misconception that simply *doing* an inquiry-based activity entails understanding of what inquiry is (Wong & Hodson, 2009, 2010). Inquiry and the NRC (2000) states that content standards for science as inquiry contain both *fundamental abilities* and *fundamental understandings* about scientific inquiry. Considering abilities and understanding of SI requires science educators to plan instruction from two different perspectives: *to do inquiry* and *knowing about inquiry* (Lederman et al., 2014). While "doing inquiry" simply refers to conducting experiments in science classrooms (Sadler et al., 2010), "knowing about inquiry" mostly emphasizes the epistemological domain of inquiry (Lederman et al., 2014). Abd-El-Khalick and Lederman (2000) proposed that epistemological development proves to be more effective when it is delivered explicitly instead of implementing it as a by-product of engagement in enquiry-related activities. Encouraging students to generate, develop, and justify facts in light of evidence during inquiry-based instruction enhances scientific understandings of students (Furtak et al. 2012). However, as Bell et al., (2003) stated, epistemic demand alone may not be enough to change students' views about SI because students might be able to focus on the task at hand without considering the broader context and implications of their work that needs systematic reflection upon their actions. Therefore, any teaching strategy that will improve student learning must consider both their cognitive demands and higher order thinking skills. When engaging in an inquiry process, learners actively develop their understanding of science by combining scientific knowledge with higher order reasoning and thinking skills (NRC, 1996; Penn et al., 2019). Typically, asking students to reflect and explicitly monitor their own learning performance supports the development of students' "how to learn" abilities (Lin & Lehman, 1999; Zion et al., 2005). According to Keselman (2003) and Zion et al. (2005), having this "how to learn" ability similarly supports students in becoming reflective inquirers. Thus, processes that mutually feed and develop each other are formed. Beyond teaching by telling and learning by memorizing, it is only possible for students to monitor their own learning, be clearly aware of their understanding, and make necessary corrections in an inquiry learning environment (Weinbaum et al. 2004).

Even though development of a thorough understanding about SI is intuitively connected with doing of inquiry, literature still is not unequivocal that engaging in inquiry leads to understanding about inquiry (Lederman et al. 2019).Schwartz et al. (2008) identified the fundamental understandings that learners should develop about SI using the reform documents (NRC, 2000) and the research on practicing scientists (Dunbar, 2001). Then, they not only described the aspects of *nature of scientific inquiry* (NOSI) for the first time but also developed the framework for the *views of scientific inquiry* (VOSI) questionnaire (Schwartz et al., 2008). The framework included six aspects of NOSI: (a) scientific investigations are guided by questions, (b) scientists use multiple methods, (c) there are multiple purposes behind scientific investigations, (d) scientific knowledge is justified with evidence and data, (e) recognition and handling of anomalous data is a critical part of progress in science, (f) there is difference between data and evidence, and (g) there is a community of practice impacting scientific inquiry. Lederman et al. (2014) examined the NOSI framework, revised some aspects, and identified brand new aspects in line with the literature. They utilized the revised framework for constructing a new tool named *views about scientific inquiry* (VASI) questionnaire that included the following aspects of scientific inquiry: (1) scientific investigations all begin with a question and do not necessarily test a hypothesis; (2) there is no single set of steps followed in all investigations (i.e., there is no single scientific method); (3) inquiry procedures are guided by the question asked; (4) all scientists performing the same procedures may not get the same results; (5) inquiry procedures can influence results; (6) research conclusions must be consistent with the data collected; (7) scientific data are not the same as scientific evidence; and that (8) explanations are developed from a combination of collected data and what is already known. The aspects of NOSI and the VASI instrument are suitable and useful for K-12 science classrooms (Lederman et al., 2014).

Policy documents in both the USA and Turkey (e.g., Ministry of National Education [MoNE], 2018a; NRC, 2012) have emphasized the need for development of abilities in students required to make inquiry and also a thorough understanding about different aspects of SI. In Turkey, starting from 2005, SI became a prominent focus and basis of science teaching in middle school science curriculum (MoNE, 2005; 2013; 2018a). Transforming teaching in elementary and secondary schools under centralized curricula of several subject matters was targeted, by the Ministry of Education, towards inquiry-based teaching. According to this curriculum "students understand how scientist produce scientific knowledge, the scientific process and how the scientific knowledge is used in the research" (MoNE, 2018a, p. 9).

Not only in science, but also in mathematics, social sciences, and Turkish language curricula, scientific inquiry-oriented standards are frequently mentioned. For example, while "creating proper research questions and obtaining appropriate data" (MoNE, 2018b) is emphasized in the 6th grade mathematics curriculum, "the importance of scientific thinking skills should be emphasized" (MoNE, 2018c) is included in the 5th grade social sciences curriculum. Similarly, with the acquisition of "questions the reliability of information sources" (MoNE, 2018d) in the 6th and 7th grade Turkish language curriculum, benchmarks directly state that students should make inferences based on scientific thought and data.

To clarify the current situation on scientific inquiry in Turkey, many studies have focused on Turkish teachers' views on scientific inquiry and textbooks. Teachers and textbooks are the most important components in the process of integrating SI into their classrooms and developing students' understanding of SI. Science teachers generally have naïve and eclectic views of the SI aspects in Turkey (Cigdemoglu & Koseoglu, 2019; Mesci & Erdas-Kartal, 2021). Social science teachers' understanding of SI was similar to science teachers (Bayram, 2021). Research demonstrates that neither science nor social science teachers in Turkey hold informed views of SI. Further, Onder et al. (2022) focused on determining the science process skills in science textbooks (3rd–8th grades) at primary and middle school levels. They revealed that the activities in these textbooks were at the basic level of science process skills (e.g., observing). In addition, the science process skills suggested in Turkish science curricula could not be integrated into the primary and middle schools' science textbooks.

### Relationship Between Understandings About SI and Academic Achievement

One of the important dimensions of inquiry-based teaching is related to students' acquisition of content knowledge (conceptual domain). According to Briggs (1979), learning outcome generally means academic achievement which includes the efficiency acquired and results obtained after the learning and assessment processes in educational institutions. Later, Reigeluth (1983) proposed that learning outcome can also be considered as an effect which serves to be a measure of the value of the approach used in varying conditions. Moreover, there is always an expected and a real outcome. To improve learning outcomes in school settings, several learning models and teaching strategies have been developed over time. Inquiry-based instruction as one of the pedagogical approaches has been utilized to teach content knowledge and improve students' skills of inquiry for decades (Bybee, 2006).

The research showed that there is a relationship between doing scientific inquiry and acquiring content knowledge (e.g., Furtak et al., 2012; Minner et al., 2010). But there is no consensus among researchers about the effectiveness of inquiry-based teaching in science learning (e.g., Kirschner et al., 2006). Superiority of innovative inquiry-based processes over traditional methods of teaching science has been proven through experimental studies (Furtak et al., 2012; Lazonder & Harmsen, 2016). Still, research based on international large-scale assessments (ILSA) sometimes show that lower scientific achievement is associated with SI-based education (Cairns & Areepattamannil, 2019; Chi et al., 2018).

The results of ILSA studies indicated that the relationship between scientific inquiry and science achievement is not linear (Cairns, 2019). However, the meta-analysis studies which have investigated the effect of inquiry-based education and used this teaching approach as a treatment condition on students show that this method helps in achieving positive outcomes (Furtak et al., 2012; Geier et al., 2008; Shymansky et al., 1983; Weinstein et al., 1982). As compared to these reports of positive effects associated with inquiry-based education, a number of cross-sectional studies have demonstrated that frequency of students treated with inquiry-based

teaching is inversely related with science literacy. These studies have used PISA data (Areepattamannil et al., 2011; Cairns & Areepattamannil, 2019; Lavonen & Laaksonen, 2009). During these studies, researchers have utilized the inquiry-based education scaled index serving as a predictor measure and have assumed a linear relationship with science achievement. For instance, inverse relationship has been reported during a study between frequency of exposure to inquiry-based education and science achievement. The researchers concluded that if students have little experience of inquiry-based education, they can score better in their science tests (Cairns & Areepattamannil, 2019). Still, it has been shown that a complicated relationship exists between different variables included in large-scale international assessments (Caro et al., 2016) and is likely to be non-linear. For instance, Jerrim et al. (2019) carried out a longitudinal study based on exploration of the influence of inquiry-based education on results of science tests in England. According to this study, even though significant association was not detected between the frequency of exposure to inquiry-based education and science achievement, a small positive association was detected in case of students who were exposed to inquiry-based education and increased degree of teacher support.

Literature indicates significant variation in context of the success of inquiry-based instruction. The main reason for this is that the inquiry-based teaching approach has various dimensions and it is difficult to include all of these dimensions together in practice. As mentioned above—in addition to other cognitive domains—SI practices also have an impact on students' higher order reasoning and thinking skills. Therefore, our argument is that these skills can be extended to other disciplines once it develops in one. In other words, the understanding of SI might be related to not only science achievement but also general academic achievement. Hence, investigating the relationship between understanding of scientific inquiry and academic achievement become crucial. This study, primarily aims to report Turkish middle school graduates' understandings of scientific inquiry. Furthermore, since literature has inadequate reports not only on the effect of scientific inquiry on academic achievement but also insufficient evidence on the relationship between understanding the nature of scientific inquiry and academic achievement, more generalizable studies are needed. Therefore, the second aim of the study is to evaluate the hypothesized relationship between students' understandings of SI and academic achievement.

## Method and Data Collection

Descriptive and inferential statistical approaches were used in the data analysis procedure. The sample of the study was selected by convenient sampling techniques among high schools with different orientations in Istanbul. Istanbul is the biggest city with a diverse population of more than 18 million. Istanbul receives most of the migration from other regions of Turkey; therefore, probably, it is the most representative of the general population of Turkey.

Similarly, high schools with different orientations (general high school, Imam Hatip high school, industrial vocational high school, science high school—three of each school) were selected to represent cultural and social fabric in a most

homogenous manner based on the principles of best representation of the population, accessibility, and willingness to participate. According to a recent report, the distribution of students to types of high schools in Turkey is as follows: 51.24% in general high schools, 16.18% in Imam Hatip high schools, 25.13% in industrial vocational high schools, and 7.43% in science high schools (MoNE, 2022). As seen in Table 1, 1480 (48.3%) students were from general high school, 469 (15.3%) from Imam Hatip high school, 750 (24.5%) from industrial vocational high school, and 368 (12%) from science high school students. These school type ratios in our sample resonate with the population ratios and demonstrate the representativeness of the sample of the study. Among the relevant high school types in Istanbul, easily accessible ones were determined by the research team, and approximately 4500 paper copies of the data collection instrument were sent to the schools. After eliminating the incomplete or inadequate instruments, the students who were absent from class on the data collection days, and the students who did not wish to participate in the study, the sample of the study was consisted of 3067 students. Additionally, 1111 (36.2%) participants were girls and 1956 (63.8%) were boys.

## Data Sources and the Questionnaire

The students' academic achievement was operationally defined as the scores they received in the High School Entrance Exam (HEE). HEE is a multiple-choice test which consists of 90 questions from the subject areas of Turkish Language (20), Mathematics (20), Science (20), History (10), English (10), and Religious Culture and Moral Knowledge (10). The test scores range from 0 to 500. In Turkey, each year approximately 1,500,000 students who have completed eighth grade take the HEE. They are competitively placed in high schools according to their scores from this test.

VASI scale developed by Lederman and colleagues (2014) was applied to determine the participants' understandings about scientific inquiry. Translation and adaptation of the scale into Turkish was conducted by Han-Tosunoglu et al. (2017). The scale consists of 7 open-ended questions. Question 1 (1a, 1b, 1c) consists of 3 subquestions, while question 3 (3a and 3b) and question 7 (7a and 7b) consist of 2 subquestions. The 8 aspects of scientific inquiry in the VASI scale and the questions on which these aspects are measured are given in Table 2.

**Table 1** Description of the participants

| | | Frequency | Percent |
|---|---|---|---|
| Gender | Girls | 1111 | 36.2% |
| | Boys | 1956 | 63.8% |
| School type | General high school | 1480 | 48.3% |
| | Imam Hatip high school | 469 | 15.3% |
| | Industrial vocational high school | 750 | 24.5% |
| | Science high school | 368 | 12% |
| | Total | 3067 | 100% |

**Table 2** Aspects of VASI questionnaire and related questions (Lederman et al., 2014, p. 76)

| Number | Aspect of scientific inquiry | VASI item# |
|---|---|---|
| 1 | Scientific investigations all begin with a question but do not necessarily test a hypothesis | 1a, 1b, 2 |
| 2 | There is no single set and sequence of steps followed in all scientific investigations (i.e., there is no single scientific method) | 1b, 1c |
| 3 | Inquiry procedures are guided by the question asked | 5 |
| 4 | All scientists performing the same procedures may not get the same conclusions | 3a |
| 5 | Inquiry procedures can influence the conclusions | 3b |
| 6 | Research conclusions must be consistent with the data collected | 6 |
| 7 | Scientific data are not the same as scientific evidence | 4 |
| 8 | Explanations are developed from a combination of collected data and what is already known | 7a, 7b, 6 (potentially) |

Students' responses were analyzed, and their understandings were categorized as naïve, eclectic, and informed based on evaluation form developed by Lederman et al. (2014, p.78). Naïve opinions were scored as "0," eclectic opinions as "1," and informed opinions as "2" and used for descriptive analysis. All collected data were analyzed by two different raters (authors), and inter-rater agreement was more than 80% for each aspect. The researchers discussed their disagreements until they reached full agreement (100%). Table 3 provides examples of how students' responses were categorized in each dimension. Additionally, in the first part of the scale, the students were asked to fill in some demographic information such as gender and HEE scores. The data were collected in the first 2 weeks of the first semester of high school in accordance with the purpose of the study. In this context, at the beginning of the academic year, the necessary permissions were obtained, and data were collected with the help of teachers at the school. The data collection process was followed directly by the authors.

Statistical data analysis started with checking the data for normality assumption in order to decide using parametric or nonparametric methods. Since data was normally distributed, parametric methods are used in analysis. While descriptive statistics were used to analyze students' understandings about scientific inquiry and academic achievement scores, inferential statistical techniques were used to make group comparisons and to determine the relationship between variables. Firstly, independent sample *t*-test was used in order to compare academic achievements of gender groups. Secondly, chi-square test was used in order to compare student's understandings about scientific inquiry between gender groups. Lastly, one-way ANOVA was performed to compare student's understandings about scientific inquiry and their academic achievement scores. Since the variances turned out to be not equally distributed in the ANOVA test, the Tamhane test was used for multiple comparisons.

## Findings

Academic achievement scores of the participants are presented in the Table 4. Student's HEE test scores ranged from 110 to 500. The average of the scores was calculated as $X = 284.13$ (Sd = 100.34).

Independent sample *t*-test results showing how academic achievement scores vary according to gender are presented in Table 5. The difference between girls and boys academic achievement mean scores was found to be statistically significant ($t = -10.661$; $p < 0.05$). While the academic achievement mean score of the girls was $X = 309.30$, it was calculated $X = 269.84$ for boys, and the difference was found to be in favor of girls.

In order to determine the participants' understandings about scientific inquiry, the aspects in the VASI scale were analyzed separately (Fig. 1). As seen, most of the students in all aspects expressed naïve opinions. The highest naïve view was calculated in the "begin with a question" (78.5%) aspect. In this aspect, 15.6% of the students stated that scientific research always start with a question. The "multiple methods" aspect, which relates that scientist can use different methods, had another one of the highest naïve scores (76.1%), while at the same time, it included the least

**Table 3** Examples of student responses for each category of SI

| Aspects of SI | Naïve views | Eclectic views | Informed views |
|---|---|---|---|
| Multiple methods | "Certainly not, because science is a serious thing." | "Yes, more than one method can be followed. First, we think, then we do experiments, make observations, collect data to prove what we think, in short, we use more than one scientific method." | "For example, various experiments are carried out while investigating the effects of sulfur hexafluoride. But Sacha Dench's research into declining geese is based on observations. It is different because one is based on experiments and one is based on observations." |
| Begin with a question | "I agree with the student who said no. The reason is that scientific research cannot only consist of scientific questions." | "I agree with the student who answered no. Because when we approach life with philosophy, I can find many answers. And a few of these answers are based on science. It may not always be a scientific question." | "I agree with those who say yes because research starts by wondering about something. The research is also carried out on a specific question and the methods to be applied on the question are determined." |
| Scientists influence results | "… they have to reach. Because they both find the same answer on the same question and data." | "Yes, if we ask each question the same and collect data in the same process, there is a small chance." | "No, if the points of view are different, the result will be different." |
| Procedures influence results | "Yes, they reach the same conclusions. Since there is only one question, they reach the same conclusion." | "it could be. Because some scientific results may change. Some do not change. Therefore, it differs according to the type of research." | "No, because both the processes and their thoughts are different." |
| Data and evidence | "No, because they both mean the same thing." | "Evidence is proof, data is information about that study." | "Data is the source of evidence… In summary, data means results. Evidence means using the power of proof of data." |
| Questions guide procedures | "Team B. Because they tried three ways, the other might be designed for one way. But B may have been designed in three ways." | "A. The tire bursts not because of the road, but because of quality." | "I believe A is better than research group B because they have to try different brands of tires." |

**Table 3** (continued)

| Aspects of SI | Naïve views | Eclectic views | Informed views |
|---|---|---|---|
| Conclusion data conformity | "I choose option c. The growth of the plant is not exactly proportional to the daylight, as the rate of elongation or shortening of the plant changes indefinitely as the daylight increases over time." | "I choose option b. Flowers need neither too much nor too little sunlight. It is more efficient when we balance it." | "I say option b. I came to this conclusion by looking at the table …" |
| Explanations | "Fig. 1 because dinosaurs have short fore-limbs." | "Dinosaurs' arms are shorter than their legs. In Fig. 2, they cannot walk with their feet anyway." | "Fig. 1 …they may have started from their own knowledge, researches, articles they read and scientific theses." |

**Table 4** Descriptive of participants' academic achievement scores

| | *N* | Min | Max | Mean | Sd |
|---|---|---|---|---|---|
| Academic achievement | 3067 | 110 | 500 | 284.13 | 100.34 |

**Table 5** Comparison of academic achievement scores according to gender

| Gender | *N* | Mean | Std. deviation | df | *t* | *p* |
|---|---|---|---|---|---|---|
| Girls | 1111 | 309.30 | 104.999 | 3065 | – 10.661 | .000 |
| Boys | 1956 | 269.84 | 94.681 | | | |

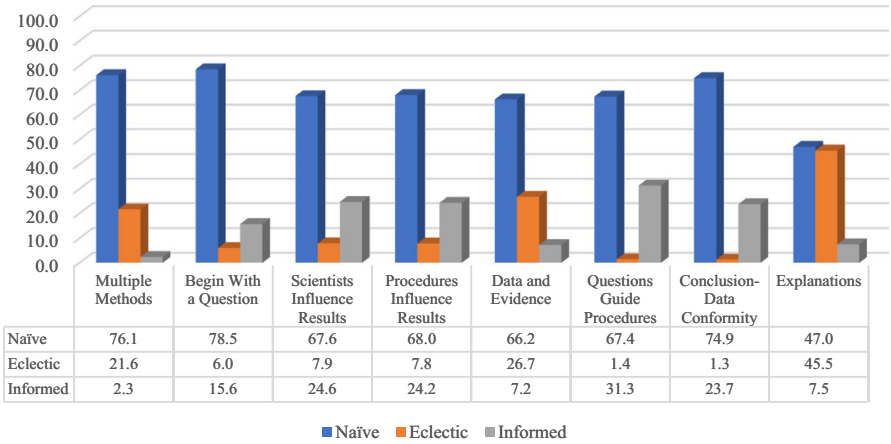


**Fig. 1** Classification of the participants in each aspects of SI

informed (2.3%) opinions of the study. Similarly, another aspect in which naïve views were presented at a high rate was the "questions guide procedures" (67.4%). In this aspect, however, the highest informed rate of the study was calculated (31.3%). In the "explanations" aspect, which is related to the explanations developed by scientists based on their prior knowledge and the data they have obtained, it was found that substantial part of the students had eclectic views (45.5%). In this aspect, it was observed that the naïve responses were still higher (47%), while 7.5% of the students were categorized as informed. Majority of students (76.1%) failed to indicate the features of controlled experiments and how scientists use multiple ways to create scientific knowledge. Experiment as a term was not usually used, by these students, to refer a specific set of procedures; instead it was used in lieu of investigation, research, or inquiry. Moreover, the students frequently stated that there would be only one method that could be chosen according to the nature of the question asked. As an example, a student from industrial vocational high school stated that " …if you are looking for an answer to a specific question, there is only one method to that question" (Student[S]-1745). Although some students mentioned multiple methods for doing science, they were not able to provide examples. Similarly, very

high portion of the participants (78.5) demonstrated naïve understandings in "starts with a question" aspect of scientific inquiry by indicating that research question is not always necessary, and scientist can ask questions later on during their investigations. A science high school student claims this idea that research questions can also be formed during the study process, saying, "You can start from where you want to start your research. For example, you first see a situation in the world, you can investigate the reasons for it and then you can create questions" (S-1806). Third, scientist influence the results, and fourth, procedures influence the results; aspects that are tested in the VASI are closely associated, and students showed very similar naïve understandings (67.6% and 68.0%, respectively) in both aspects by failing to articulate the role of interpretation in science and how different data collection procedures may impact the observed results. For example, S-1498 said, "If scientists are doing the same thing, they should reach the same conclusion," and in another question, student supported that similar processes should give the same result by saying "all roads lead to the same in such a case." Compared to the other aspects, more students showed that informed understanding (31.3%) in procedures is guided by the research questions aspect. Informed answers to this dimension generally consisted of statements parallel to student 1620's answer, "The research process followed by group A is better than the other. Because the research of group B is not relevant to the subject." However, the majority of the participants (%67.4) were still unsuccessful in connecting research question and the method of the investigation. Findings showed that establishing the distinction between the data and evidence was difficult for the students as only 7.2% of them indicated informed responses to this aspect of scientific inquiry.

Relatively high (26.2%) percentage of the students had eclectic understandings apparent in their unsystematic usage of the terms data, facts, evidence, and proof. They often used the terms correctly and incorrectly in their explanations at the same time. Students also fell prey to the data conformity (74.9%) by ignoring the question and the data provided in the question in forming their conclusion and reaching to a decision. Instead of evaluating the available data, they operationalized their everyday knowledge about plants and photosynthesis.

Pearson's chi-square analysis results regarding the relationship between participants' understandings of each aspect of SI and gender are presented in Table 6. As can be seen, the correlation between variables was found to be statistically significant ($p < 0.05$). For the multiple methods dimensions, the majority of the responses were in "naïve" category.

While the distribution of informed and eclectic answers within gender was similar, 70.3% of girls and 79.4% of boys gave naïve answers in this dimension. Similarly, boys had more naïve understandings than girls, respectively: 71.6–82.4% for "begin with a question," 57.0–73.6% for "scientists influence results," 61.3–71.8% for "procedures influence results," 59.2–70.1% for "data and evidence," 57.9–72.8% for "questions guide procedures," and 70.4–77.5% for "conclusion data conformity" dimensions. Finally, unlike the other dimensions, the majority of responses were in "eclectic" category for "explanations" dimension, and it was calculated that 50.4% of girls and 42.7% of boys had eclectic understandings about this dimension. Finally, the ANOVA analysis for the group comparisons of the participants' understandings

**Table 6** The relationship between participants' understandings of each aspect of SI and gender

| | | | Naïve | Eclectic | Informed | Sig |
|---|---|---|---|---|---|---|
| Multiple methods | **Girls** | Count | **781** | **301** | **29** | .000 |
| | | %within gender | 70.3% | 27.1% | 2.6% | |
| | | % within multiple methods | 33.4% | 45.5% | 40.8% | |
| | **Boys** | Count | **1554** | **360** | **42** | |
| | | % within gender | 79.4% | 18.4% | 2.1% | |
| | | % within multiple methods | 66.6% | 54.5% | 59.2% | |
| Begin with a question | **Girls** | Count | **796** | **83** | **232** | .000 |
| | | %within gender | 71.6% | 7.5% | 20.9% | |
| | | % within begin with a question | 33.1% | 45.4% | 48.6% | |
| | **Boys** | Count | **1611** | **100** | **245** | |
| | | % within gender | 82.4% | 5.1% | 12.5% | |
| | | % within begin with a question | 66.9% | 54.6% | 51.4% | |
| Scientists influence results | **Girls** | Count | **633** | **115** | **363** | .000 |
| | | % within gender | 57.0% | 10.4% | 32.7% | |
| | | % within scientists influence results | 30.6% | 47.7% | 48.1% | |
| | **Boys** | Count | **1439** | **126** | **391** | |
| | | %within gender | 73.6% | 6.4% | 20.0% | |
| | | % within scientists influence results | 69.4% | 52.3% | 51.9% | |
| Procedures influence results | **Girls** | Count | **681** | **105** | **325** | .000 |
| | | %within gender | 61.3% | 9.5% | 29.3% | |
| | | % within procedures influence results | 32.6% | 43.8% | 43.9% | |
| | **Boys** | Count | **1405** | **135** | **416** | |
| | | %within gender | 71.8% | 6.9% | 21.3% | |
| | | % within procedures influence results | 67.4% | 56.3% | 56.1% | |
| Data and evidence | **Girls** | Count | **658** | **338** | **115** | .000 |
| | | %within gender | 59.2% | 30.4% | 10.4% | |
| | | % within data and evidence | 32.4% | 41.3% | 52.3% | |
| | **Boys** | Count | **1371** | **480** | **105** | |
| | | %within gender | 70.1% | 24.5% | 5.4% | |
| | | % within data and evidence | 67.6% | 58.7% | 47.7% | |
| Questions guide procedures | **Girls** | Count | **643** | **15** | **453** | .000 |
| | | %within gender | 57.9% | 1.4% | 40.8% | |
| | | % within questions guide procedures | 31.1% | 35.7% | 47.2% | |
| | **Boys** | Count | **1423** | **27** | **506** | |
| | | %within gender | 72.8% | 1.4% | 25.9% | |
| | | % within questions guide procedures | 68.9% | 64.3% | 52.8% | |

**Table 6** (continued)

| | | | Naïve | Eclectic | Informed | Sig |
|---|---|---|---|---|---|---|
| Conclusion data conformity | **Girls** | Count | **782** | **16** | **313** | .000 |
| | | %within gender | 70.4% | 1.4% | 28.2% | |
| | | % within conclusion data conformity | 34.0% | 39.0% | 43.0% | |
| | **Boys** | Count | **1516** | **25** | **415** | |
| | | %within gender | 77.5% | 1.3% | 21.2% | |
| | | % within conclusion data conformity | 66.0% | 61.0% | 57.0% | |
| Explanations | **Girls** | Count | **433** | **560** | **118** | .000 |
| | | %within gender | 39.0% | 50.4% | 10.6% | |
| | | % within explanations | 30.0% | 40.1% | 51.3% | |
| | **Boys** | Count | **1008** | **836** | **112** | |
| | | %within gender | 51.5% | 42.7% | 5.7% | |
| | | % within explanations | 70.0% | 59.9% | 48.7% | |

0 cells (0.0%) have expected count less than 5

(naïve, eclectic, and informed) in each aspect of SI according to their academic achievement results are presented in Table 7. As can be seen, differences between the academic achievement scores of the participants for the categorized SI understandings were statistically significant in 7 sub-dimensions ($p < 0.05$). The academic achievement scores of the participants did not show a statistically significant difference only in the "conclusion data conformity" sub-dimension ($F = 1.488$; $p > 0.05$). The identified differences for the "multiple methods," "begin with a question," "data and evidence," and "explanation" sub-dimensions were found significant among all subgroups. In all of these subgroups, the informed students had the highest average academic achievement score, the eclectic had a moderate score, and the naïve had the lowest.

However, academic achievement scores of the students were not significantly different for informed and eclectic groups in "scientists influence results," "procedures influence results," and "questions guide procedures" sub-dimensions. This difference was only statistically significant for those students who have naïve understandings.

## Discussion and Conclusion

Given the importance of understanding SI in promoting scientific literacy, the purpose of this study was twofold: first, the study aimed to report on Turkish middle school graduate students' understanding of SI. Second, the study aimed to assess whether there is a relationship between understandings of SI and academic achievement.

**Table 7** Group comparisons of the participants' understandings in each aspect of SI according to their academic achievement

| | | *N* | % | Mean | Sd | *F* | *p* | Post hoc |
|---|---|---|---|---|---|---|---|---|
| Multiple methods | *Naïve* | 2335 | 76.1 | 265.80 | 90.55 | 205.982 | .000 | Informed-eclectic |
| | *Eclectic* | 661 | 21.6 | 335.29 | 107.47 | | | Informed-naïve |
| | *Informed* | 71 | 2.3 | 411.04 | 80.18 | | | Eclectic-naïve |
| Begin with a question | *Naïve* | 2407 | 78.5 | 265.34 | 88.07 | 299.117 | .000 | Informed-eclectic |
| | *Eclectic* | 183 | 6.0 | 287.10 | 95.92 | | | Informed-naïve |
| | *Informed* | 477 | 15.6 | 377.86 | 107.37 | | | Eclectic-naïve |
| Scientists influence results | *Naïve* | 2072 | 67.6 | 268.36 | 94.45 | 83.472 | .000 | Informed-naïve |
| | *Eclectic* | 241 | 7.9 | 312.70 | 108.11 | | | Eclectic-naïve |
| | *Informed* | 754 | 24.6 | 318.35 | 103.01 | | | - |
| Procedures influence results | *Naïve* | 2086 | 68.0 | 273.63 | 98.35 | 37.910 | .000 | Informed-naïve |
| | *Eclectic* | 240 | 7.8 | 297.52 | 98.33 | | | Eclectic-naïve |
| | *Informed* | 741 | 24.2 | 309.38 | 101.62 | | | - |
| Data and evidence | *Naïve* | 2029 | 66.2 | 267.40 | 92.48 | 154.853 | .000 | Informed-Eclectic |
| | *Eclectic* | 818 | 26.7 | 299.57 | 101.06 | | | Informed-naïve |
| | *Informed* | 220 | 7.2 | 381.14 | 103.48 | | | Eclectic-naïve |
| Questions guide procedures | *Naïve* | 2066 | 67.4 | 257.80 | 84.35 | 255.675 | .000 | Informed-naïve |
| | *Eclectic* | 42 | 1.4 | 315.43 | 103.97 | | | Eclectic-naïve |
| | *Informed* | 959 | 31.3 | 339.51 | 108.68 | | | - |
| Conclusion data conformity | *Naïve* | 2298 | 74.9 | 283.95 | 103.14 | 1.488 | .226 | - |
| | *Eclectic* | 41 | 1.3 | 258.54 | 69.42 | | | - |
| | *Informed* | 728 | 23.7 | 286.16 | 92.41 | | | - |
| Explanations | *Naïve* | 1441 | 47.0 | 246.06 | 77.23 | 340.382 | .000 | Informed-eclectic |
| | *Eclectic* | 1396 | 45.5 | 304.86 | 101.44 | | | Informed-naïve |
| | *Informed* | 230 | 7.5 | 396.87 | 100.44 | | | Eclectic-naïve |
| Total | | 3067 | 100.0 | 284.13 | 100.34 | | | |

The results of the investigation revealed that middle school graduate students generally do not have adequate understandings regarding SI. Indeed, the majority of the students expressed naïve opinions on all aspects of SI. In particular, the most naïve views were for "begin with a question," "multiple methods," and "conclusion data conformity." Although students demonstrated relatively more informed or eclectic views on aspects such as "explanations" and "procedures influence results," their overall understandings of SI were far from expected. Considering that in the 9th grade, the students in Turkey complete a significant part of their compulsory education, one expects that, by the 9th grade, students should have formed informed opinions on at least some of the aforementioned SI aspects. These results indicate that science education in Turkey is insufficient to develop students' understanding of SI. On the other hand, the fact that Turkish students' understanding of SI is found to be insufficient in this study is consistent with the findings of most of international studies conducted with VASI questionnaire. Indeed, many recent studies in various

countries reported poor and insufficient understandings of students regarding SI. Two large-scale international studies with seventh grade (Lederman et al. 2019) and high school students (Lederman et al. 2021), for example, revealed students from various countries held naïve views about all aspects of SI. Other national studies reached more or less the same conclusion (e.g., Andrade et al., 2020; Gyllenpalm et al., 2022).

Looking at results of previous research and discussions, one can easily grasp that there are many factors contributing this failure. One of the major factors, perhaps, could be related to general aims of and approaches to education. In Turkey, for example, despite various attempts to reform compulsory education, science education at all levels continues to focus on teaching science content with the sole purpose of preparing students for high-stakes exams, with no explicit attention paid to the development of understandings and skills related to science and SI (Alisir & Irez, 2020; Dogan, 2021). Teachers frequently overlook the SI process in favor of teaching the products of science. Teachers' understanding of science and the nature of scientific inquiry could be another important factor. Research evidence indicates that many science teachers in Turkey, like their counterparts all around the world, enter science classrooms without a clear conception of the nature of their own discipline (Irez, 2009). Their inconsistent understandings have potential to manifest themselves in classroom practice, either indirectly or openly. Research evidence shows that students are favorably affected by their teacher's inferred philosophy of science, even if the teacher does not attempt to do so explicitly (Tobin & McRobbie, 1997). This suggests that teachers' unclear conceptions of science and SI may have a negative impact on their students' understandings rather than improving them. Further, research studies show that science textbooks in Turkey are full of misconceptions regarding nature of science and SI (Irez, 2009, 2016); therefore, far from improving students' understanding (Dogan, 2021). Considering the impact of textbooks on learning, it can be argued that these inadequate ideas presented in the textbooks could affect student understanding of SI negatively in both direct and indirect ways. Lastly, many researchers discuss that the way SI is communicated in science classes could also be another factor behind students' poor understanding of SI. Researchers discuss that using an implicit approach in teaching SI, which assumes that students' engagement in scientific practices automatically develops their understandings of SI, is ineffective (Concannon et al., 2020). Rather, similar to discussions on nature of science teaching, the aspects of SI should be embedded in the curriculum and explicitly taught. Indeed, various studies (Concannon et al., 2020; Lederman et al., 2014) illustrated that explicit instruction of SI, in which discussion and critical reflection upon the aspects of SI lies at the core, is very effective in developing informed understandings regarding to SI.

Results of the study also indicated that boys had more naïve understandings comparing to girls in majority of the dimensions of SI, including "the multiple methods," "begin with a question," "scientists influence results," "procedures influence results," "data and evidence," "questions guide procedures," and "conclusion data conformity." It is important to note that while there is an established research base assessing gender differences with respect to attitudes towards science, science education, scientific subjects, and science-based careers, to the best of our knowledge

these differences have not been assessed in the context of understanding SI. However, few studies examining the impact of gender in understandings about the nature of science can provide an opportunity to compare the results obtained in this study. Some of these studies found significant gender differences as we did in our study. Results of a case study conducted by Flegg et al. (1995) in Australia, for example, indicated that male and female students view nature of science differently. The study revealed that females in the main perceive science more in terms of workable solutions to problems and its enabling power to help people. Males, on the other hand, leaned towards knowledge making, logical explanations, and new discoveries. A recent study by Cetin and Kahyaoglu (2022) on teacher candidates in Turkey reported a statistically significant difference between female and male teacher candidates' nature of science beliefs mean scores in favor of females. The study revealed that female teacher candidates possessed more informed beliefs compared to males with regards to the majority of sub-dimensions of nature of science explored in the study. These sub-dimensions included tentativeness, observation and inference, scientific method(s), assumptions and boundaries, socio-cultural embeddedness, and theories and laws. While these studies confirm the results of this study, there are also other studies reported no gender differences in understanding the nature of science. Assessing students' nature of science understandings from a gender perspective, Emran et al. (2020) concluded that both genders held similar perceptions. Similarly, the findings of a study by Manassero et al. (2010) also showed that girls and boys are not very different in understanding the nature of science. Emran et al. (2020) discuss that such contradictory findings in the research literature may be a result of differences in the educational systems and socio-cultural processes of the countries involved. While it is possible to associate findings and discussions of the research on students' understandings of nature of science with understandings of SI considering the relatedness of the constructs, possible gender differences in understanding SI and the reasons behind these is still an unexplored area which begs for research.

With regards to academic achievement, the average of the scores of the participants in the HEE was calculated as $X = 284.13$. Further analysis revealed that girls outperformed boys; the academic achievement mean score was calculated as $X = 309.30$ for the girls and $X = 269.84$ for boys, the difference being statistically significant. The professional literature is replete with studies examining gender differences with respect to academic achievement and, as our findings indicated, has revealed that females outperform males at different stages in the school system, have better grades, and reach post-school qualifications in higher numbers (e.g., Carvalho, 2016; Gibb et al., 2008; Marcenaro-Gutierrez et al., 2018; Steinmayr et al., 2014).

Several reasons for gender differences in academic achievement are discussed in the literature. Some researchers considered biological correlates, such as brain organization, relevant to gender differences in achievement (e.g., Gibb et al., 2008). Others (e.g., Steinmayr & Spinath, 2008) discussed the association between student characteristics, such as motivation and personality, and academic achievement. Various behavioral dimensions related to externalization has also been increasingly considered. Carvalho (2016), for example, discussed the gender differences in these dimensions that result, for instance, from dissimilar patterns of academic and social expectations for males and females as well as from influences of socialization in the

formation of gendered behaviors accordingly with the cultural norms for masculinity and femininity, which may cause different patterns of school behaviors and, consequently, also different patterns of achievement.

The findings indicated a statistically significant correlation between students' academic achievement scores and understandings in all aspects of SI except for the "conclusion data conformity" aspect. These findings point out a linear correlation between academic achievement and understandings of SI. It is important to point here that this study used the scores obtained in the HEE exam in determining students' academic achievement. As mentioned earlier, this exam aims to assess student academic achievement in various areas including Turkish Language, Mathematics, Science, History, English, and Religious Culture and Moral Knowledge. Therefore, this study explored the relationship between students' general academic achievement and understanding of SI. Previous research in the field, on the other hand, concentrated on the relationship between science achievement and understanding of SI. Penn et al. (2019), for instance, examined the relationship between 12th grade students' understanding of SI and achievement scores obtained from a high-stake exam in South Africa. Similar to this research, their results showed that understandings about nature of SI was positively correlated with their achievement scores in physical sciences. They concluded that learners' understandings about the nature of SI had a positive influence on academic achievements. There are also other studies indicating that informed understandings about nature of SI can lead better understandings of science content. To investigate the impact of inquiry-based science instruction on K-12 student outcomes, Minner et al. (2010) synthesized the findings of 138 research studies conducted between 1984 and 2002. They reported that teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than strategies that rely on more passive techniques, which are often necessary in today's standardized-assessment laden educational environment. Further, Cairns (2019) discussed that the greatest degree of achievement in science tests was achieved when students were allowed to describe their ideas in epistemic domain during classes. However, there are also a number of cross-sectional studies (e.g., Areepattamannil et al., 2011; Cairns & Areepattamannil, 2019; Lavonen & Laaksonen, 2009) which have demonstrated that this relationship is far from being straightforward.

While previous research has explored the relationship between science achievement and understandings of SI, more work is needed to fully understand the underlying mechanisms that link SI and general academic achievement. It may be that students who have a strong understanding of SI have better metacognitive skills that allow them to apply their knowledge across different subjects. To this end, Penn et al. (2019) argues that learners who engage in scientific inquiry describe objects and events, pose questions, create explanations, test those explanations against existing scientific knowledge, and share their ideas with others. The authors suggest that through these activities, learners use and develop higher-order reasoning and thinking skills which ultimately help them build their understanding by integrating knowledge with their own ideas and experiences. Additionally, it is possible that teachers who emphasize SI in their instruction are also using teaching methods that promote critical thinking and higher-order reasoning skills, which may explain

why students who understand SI tend to have higher academic achievement (Tobin & McRobbie, 1997). Further research is needed to examine these potential explanations and to determine how best to support students' development of SI and its impact on academic achievement.

There has been a strong agreement among science educators that understanding the nature of SI is one of the most important components of functional scientific literacy. It is assumed that understanding the nature of SI would help individuals in making informed decisions with respect to scientific claims (Lederman, 1999). Therefore, teaching about nature of science and SI has been and continues to be an emphasis in science curricula all over the world. However, the results of this study, combined with the results of many recent studies from other countries, indicate that we are quite far from achieving this goal. It seems that we should reconsider the aims of education, the structure of science curricula, the education of science teachers, and the design of learning environments and teaching materials in a way to help students gain crucial understandings and skills, such as understanding the nature of SI, that are necessary to promote scientific literacy in our societies. Failing to do so would mean that the vast majority of students will continue to graduate from schools and make decisions about socio-scientific issues with unexamined and unclear understandings of SI.

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