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International collaborative follow-up investigation of graduating high school students' understandings of the nature of scientific inquiry: is progress Being made?

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International collaborative follow-up investigation of graduating high school students' understandings of the nature of scientific inquiry: is progress Being made?

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ABSTRACT
Understandings of the nature of scientific inquiry (NOSI), as opposed to engaging students in inquiry learning experiences,

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are included in science education reform documents around the world. However, little is known about what students have learned about NOSI during their pre-college school years. The purpose of this large-scale follow-up international project (i.e. 32 countries and regions, spanning six continents and including 3917 students for the high school sample) was to collect data on what exiting high school students have learned about NOSI. Additionally, the study investigated changes in 12th grade students' NOSI understandings compared to seventh grade (i.e. 20 countries and regions) students' understandings from a prior investigation [Lederman et al. (2019). An international collaborative investigation of beginning seventh grade students' understandings of scientific inquiry: Establishing a baseline. *Journal of Research in Science Teaching*, 56(4), 486–515. https://doi.org/10.1002/tea. 21512]. This study documents and discusses graduating high school students' understandings and compares their understandings to seventh grade students' understandings of the same aspects of scientific inquiry for each country. It is important to note that collecting data from each of the 130+ countries globally was not feasible. Similarly, it was not possible to collect data from every region of each country. A concerted effort was made, however, to provide a relatively representative picture of each country and the world.

KEYWORDS
Scientific inquiry; international investigation

Introduction

Scientific inquiry (SI) refers to two different types of student outcomes. Traditionally, the focus of scientific inquiry (SI) has been on the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific literacy (Lederman, 2009). It has been strongly advocated as an important goal for students to achieve for well over a century, but students' mastery of inquiry processes and practices has generally been only moderately realised (Chinn & Malhotra, 2002). Recent reform documents have emphasised that students should not only develop the abilities necessary to do inquiry, but also develop an understanding about the nature of scientific inquiry (NOSI) (e.g. *Benchmarks for Science Literacy*, AAAS, 1993; *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, National Research Council [NRC], 2012). The National Science Education Standards (NRC, 1996) and the Inquiry and The National Science Education Standards (NRC, 2000) documents were most explicit in their differentiation between the abilities to do inquiry and knowledge about scientific inquiry and this distinction continues to be evident in the Next Generation Science Standards (NGSS Lead States, 2013). Similar distinctions are becoming more prominent in reform documents throughout the world. Although it may be assumed, but not empirically demonstrated, students will improve their ability to do inquiry if they have an understanding about what they are doing and why. Indeed, considering the goal of scientific literacy for the general public, it can be argued that knowledge about inquiry and what scientists do is more important than the ability to do inquiry. After graduating from pre-college instruction and/or college, citizens do not do investigations to make decisions about scientifically based issues (Zeidler et al., 2005). Rather, they use their knowledge of how science is done to make more informed decisions about scientifically based personal and societal decisions.

Research indicates that, much like research on understanding the nature of scientific knowledge (NOSK, also known as NOS), neither teachers nor students typically hold informed views about nature of scientific inquiry (Lederman & Lederman, 2004). The research base for NOSI is markedly smaller than that for NOSK. This small research base is partly due to both the conflation of NOSK and NOSI and the lack of a readily available, or frequently utilised, instrument similar in nature to the various forms of the Views of Nature of Science questionnaires (VNOS) (Lederman et al., 2002). One of the original instruments used to measure NOSI was the Views of Scientific Inquiry (VOSI) (Schwartz et al., 2008). The agreed upon aspects of NOSI were mapped onto the VOSI instrument which showed three aspects of NOSI were not assessed by this instrument, three aspects of NOSI that were left unaddressed by the VOSI: (a) inquiry procedures are guided by the question asked, (b) research conclusions must be consistent with the data collected, and (c) explanations are developed from a combination of collected data and what is already known. With this in mind, questions were added and/or refined to fully capture all the aspects of NOSI, this resulted in the development of the Views About Scientific Inquiry (VASI) (Lederman et al., 2014). While the scientific inquiry is inextricably linked with NOSK, what is notable is the lack of a robust research base centred on students' understandings about NOSI. What is evident is the preponderance of research focused on the doing of inquiry, which oftentimes is assumed to imply an understanding about inquiry (Bell et al., 2003). The belief that doing scientific inquiry is a sufficient condition for developing understandings about NOSI, unfortunately, is a misconception (e.g. Wong & Hodson, 2009, 2010).

The intent of this collaborative project was to report on students' understandings of NOSI across the globe. Now that a valid and reliable assessment tool is available and a baseline study of grade seven international students has been conducted (Lederman et al., 2019), it is of significant interest to see what knowledge about NOSI students gain in high school. The purpose is not to focus on comparisons across countries and regions (especially since instruction, curricula, and cultures vary widely across nations), but rather to develop a baseline of understandings worldwide.

Why should students understand NOSI, and what should they know?

Students should be able to understand how scientists do their work and how scientific knowledge is developed, critiqued, and eventually accepted by the scientific community. Scientific inquiry is this process. The content standards for Science as Inquiry for grades K-12 advocate the merit of students developing (a) the abilities necessary to do inquiry and (b) understandings about scientific inquiry (NRC, 2000). Thus, by grade 12, students need to be able to not only 'do' inquiry, but also 'know' about scientific inquiry (NOSI). Although conducting inquiry is important, students can often do inquiry without knowing how and why scientists go about their work. The efficacy of such implicit approaches to developing understandings of NOSI, and for that matter NOSK, has been called into question by a growing body of research (e.g. Abd-El-Khalick & Lederman, 2000; Akerson et al., 2000; Lederman et al., 2013). Therefore, it is important to identify and explicitly teach the aspects of scientific inquiry that can serve, in the end, to develop informed views about inquiry. And, of course, the major endpoint desired is the development of a scientifically literate citizenry.

The aspects of scientific inquiry that follow are accessible and reasonably appropriate in the context of K-12 science education and are derived from various reform documents. Specifically, students should develop an informed understanding that: scientific investigations all begin with a question but do not necessarily test a hypothesis; there is no single set or sequence of steps followed in all investigations (i.e. there is no single scientific method); inquiry procedures are guided by the question(s) asked; all scientists performing the same procedures may not get the same results; inquiry procedures can influence results; research conclusions must be consistent with the data collected; scientific data are not the same as scientific evidence; and explanations are developed from a combination of collected data and what is already known. These aspects of NOSI are aligned with what is typically advocated in science education reform documents and is the focus of the VASI questions, They are not meant to be a definitive list of outcomes with respect to inquiry but, there is little debate about the importance of these aspects of inquiry and research has shown they are accessible to pre-college students within the context of existing curricula (NGSS Lead States, 2013). See appendix A for the VASI questionnaire.

Statement of the problem

Although the teaching of scientific inquiry is valued around the world, there has only been one international assessment of what students actually know as they begin grade seven (Lederman et al., 2019). The present study sought to examine high school students' understandings, at the beginning of their final school year, of NOSI in various countries worldwide. This study provides data on what, if anything, students learn about NOSI by the completion of pre-college science education, from which instructional, curricula, and policy decisions can be made. The data collected here also allow for a comparison with the data collected by Lederman and colleagues (2019) focused on grade seven students.

Method

An important caveat about sampling and methodology

As most of you already know, the best intentions are often difficult to achieve when attempting to coordinate data collection in 32 different countries and regions throughout the world. There are numerous local restrictions and complexities, such as school sizes, class sizes, curricula, and school administrations that enter into research designs, let alone differences in culture and language. Consequently, although we requested a sample of 100 students from each research site we often received slightly less or more. We also requested samples of what would be considered 'average ability' (or generally representative) students from each site. As you know, this is often not always possible and researchers end up taking what they can get and then accommodating during data analysis/interpretation. Furthermore, a strong argument can be made that what is considered 'average ability' in one location is not equivalent to 'average ability' in another. Students considered of 'average ability' in Sweden are not equivalent to students of 'average ability' in Chicago. This is not genetics, but rather the result of school systems, curricula, teaching, etc. As the data will show, regardless of variability across samples, the results were fairly consistent, making the findings more robust than if the samples had been homogeneous.

Sample

There were approximately 100 students sampled from each country that represents every continent around the world, with the exception of Antarctica. The research sites were: Australia ($n = 91$), Austria ($n = 113$) Brazil ($n = 445$), Bulgaria ($n = 105$), Canada ($n = 90$), Chile ($n = 111$), China (Beijing) ($n = 110$), China (Shanghai) ($n = 120$), China (Zhejiang) ($n = 124$), Colombia ($n = 100$), Egypt ($n = 101$), England ($n = 136$), Fiji ($n = 100$), Finland ($n = 107$), France ($n = 106$), Germany ($n = 88$), Greece ($n = 100$), Hong Kong ($n = 100$), Israel ($n = 88$), Japan ($n = 138$), Mexico ($n = 102$), Nigeria ($n = 55$), Peru ($n = 108$), Philippines ($n = 100$), South Africa (Western Cape) ($n = 110$), South Africa (Johannesburg) ($n = 203$), Spain ($n = 121$), Sweden ($n = 145$), Taiwan ($n = 110$), Thailand ($n = 117$), Turkey ($n = 119$) and US ($n = 154$). The total sample size of high school students was 3917 students. The students who were selected for this study were representative for their region; their selection was based on average academic ability, representative diversity of the region and socioeconomic background. It is important to note that, because of differences across countries/regions, the sample size is not the number of students, but rather the number of countries/regions.

Data collection

There were a total of 32 primary contact people participating in this study, one contact person in each country, who almost always worked with a team of colleagues. Each site had one city with the exception of South Africa which had two sites. China had three sites. In the countries with multiple sites, there were several contact people. The contact people across the six continents were responsible for; completion of training in the coding of the VASI, language translation/back translation for VASI validity, selection of a representative, sample, data collection (including paper and pencil assessments and individual interviews), data analysis, and the writing of location-specific aspects of the results. The selection of the contact people and the training of the contact people for the scoring of the VASI were completed by the U.S. researchers. This research began with an initial meeting at a large science education research meeting. There, the initial timeline of the study was laid out. Then individual meetings were arranged and conducted via videoconferencing between each site and the primary U.S. site. The first meeting involved learning to administer and score the VASI. The subsequent meetings involved scoring at least 10 of the site's VASIs between the U.S. researchers and the other research group until a confirmed 80% or greater inter-rater agreement was established. If additional meetings were needed, they were scheduled on a case by case basis. This study took place at the start of the high school academic year which varied in timing depending on the start time of the school year in the various continents and hemispheres.

The primary contacts were selected based on the documented active research programs of the people in each country.

Each student was given a VASI to complete in a 60-min time period. The VASI was given in the students' language of science instruction. When the language spoken was not English, the instrument was translated and then back translated to verify the accuracy of the translation. The translation and back translation procedures followed well-established standards (Maneersriwongul & Dixon, 2004; Organization for Economic and Co-operation and Development [OECD], 2017). A sample question from the VASI is used here to illustrate the degree to which respondents understand the NOSI aspect that procedures followed in a scientific investigation need to be guided by the question that is asked. The question reads, 'Two teams of scientists are walking to their lab one day and they saw a car pulled over with a flat tire. They all wondered, 'Are certain brands of tires more likely to get a flat?' Team A went back to the lab and tested various tires' performance on one type of road surfaces. Team B went back to the lab and tested one tire brand on three types of road surfaces. Explain why one team's procedure is better than the other one.' The response of why they selected one procedure over another is used, in part, to determine the respondents' knowledge of the NOSI aspect in question. The full VASI instrument in different languages is available online.

Data analysis

After administration of the VASI, the responses were coded by the primary contact person (and colleagues) in each country. Each student was given a code of; No Answer, Naïve, Mixed or Informed for each aspect of NOSI. If a respondent provides a response consistent across the entire questionnaire that is wholly congruent with the target response for a given aspect of NOSI they are labeled as 'informed.' If, by contrast, a response is either only partially explicated, and thus not totally consistent with the targeted response, or if a contradiction in the response is evident, a score of 'mixed' is given. A response that is contradictory to accepted views of an aspect of NOSI and provides no evidence of congruence with accepted views of the specific aspect of NOSI under examination is scored as 'naïve.' Lastly, for scores that are incomprehensible, unintelligible, or that, in total, indicate no relation to the particular aspect, a categorisation of 'no answer' is assigned. At least 20% of the students was interviewed to ensure that the coding of the aspects of NOSI was accurate. The 20% of the sample was chosen at random from the country/regions' total sample. These interviews insured face validity for the questionnaire. The interviews were recorded and transcribed. Interview data are not described if the coding is the same as the original interpretation of the VASI. Again, the purpose of the interviews was to document the face validity of the VASI, as opposed to providing additional information of students' understandings. However, if 'new' insights were revealed, interview data are discussed. The inter-rater reliability of the VASI was 80% or better for each site. In an effort to discern whether there were any differences in understanding between this investigation of high school students and the previous Lederman et al. (2019) study of grade seven students, Chi-Square tests were performed between the 'informed' understandings here and those of grade seven students. Although 20 of the countries used for these comparisons were the same for these comparisons, the students were not the same as this was not a longitudinal study, but rather a cross-sectional follow-up study with different students.

Results

Frequency data were used for each aspect of NOSI for each country/region. When there were multiple sites in a country/region the data were aggregated, unless the site contacts felt that there were large differences across locations. Each aspect of NOSI has its own data table containing a list of the participating countries/regions (Table 1). All of the frequencies for each category (naïve, mixed and informed) are represented as percentages. Not all of the percentages add up to 100 due to the fact that students left some of the questions on the VASI blank, therefore we could not categorise their answer.

Overwhelmingly, the results from this study show that students completing their last year of pre-college instruction (i.e. high school), around the world, have an overall naïve view of NOSI. There were instances in which students in a country did better than 'naïve' on a particular aspect of NOSI. These results are consistent with the studies that have been completed with secondary students, preservice and in-service teachers. The findings are not surprising since students are rarely taught NOSI in an explicit, reflective manner (Khishfe & Abd-El-Khalick, 2002; Khishfe & Lederman, 2006; Lederman et al., 2002). It is fully recognised that the context, curriculum, instructional approach, culture, etc. differs across country/region. There was no mechanism to control for such differences. Regardless of this variability, the resulting data were extremely consistent. However, the following is a brief explanation from each country/region research team explaining the possible causes to their students' understanding of NOSI. It is important to note that there was no algorithm for each research site to report their interpretations. Rather, each country/region site discussed what they felt were the best explanations for the results they obtained.

General findings

Overall, this study found that grade 12 students' understanding of scientific inquiry is less than adequate, although they do have slightly better understandings than the grade seven students studied by Lederman et al. (2019) (Table 2). However, it was apparent that, for each country or region in the study, there were some students who held more informed understandings than others. These variations differed from place to place depending on the teaching context, curriculum, and student backgrounds. The following paragraphs highlight the findings from each country/region. Each site in the study wrote their own findings section. First each country/region described their standards for Science education required by their government, sample selection, then they wrote about the most interesting findings from their country/region. Additionally, provided are possible reasons for these particular results for each aspect of NOSI measured in this study. Instructional practices were not systematically observed but some researchers chose to write about this based on their knowledge of schools and classrooms in their country/region.

Table 1. Complete set of data from each country/region for each aspect of SI.

Country/Region	n	Start with a question (%)			Multiple methods (%)			Same procedures may not yield same results (%)			Procedures influence results (%)			Conclusions must be consistent with data C. (%)			Procedure are guided by the question asked (%)			Data and evidence are not the Same (%)			Conclusions are developed from data and prior knowledge (%)		
		N	M	I	N	M	I	N	M	I	N	M	I	N	M	I	N	M	I	N	M	I	N	M	I
Australia	91	19.8	40.7	35.2	5.5	87.9	4.4	13.2	64.8	22.0	3.3	71.4	16.5	25.3	22.0	52.7	23.1	13.2	59.3	16.5	71.4	5.5	3.3	59.3	16.5
Austria	113	35.4	21.2	42.5	23.0	59.3	16.8	25.7	38.1	36.3	41.6	18.6	38.1	42.5	4.4	53.1	26.5	1.8	70.8	23.0	48.7	24.8	7.1	54.0	38.9
Brazil	445	62.9	15.1	13.9	64.0	25.2	8.5	58.2	27.9	9.0	63.1	21.8	7.2	64.5	14.8	10.8	59.6	8.3	18.7	65.2	18.2	2.0	54.2	29.7	5.6
Bulgaria	105	19.0	32.4	48.6	20.0	45.7	34.3	13.3	35.2	51.4	15.2	37.1	47.6	21.0	47.6	31.4	19.0	34.3	46.7	13.3	41.9	44.8	14.3	41.0	44.8
Canada	90	22.2	7.8	68.9	20.0	47.8	31.1	15.6	15.6	68.9	11.1	25.6	63.3	36.7	3.3	58.9	13.3	1.1	84.4	15.6	34.4	47.8	5.6	40.0	51.1
Chile	111	35.1	20.7	40.5	55.9	35.1	8.1	44.1	21.6	30.6	45.9	28.8	22.5	40.5	12.6	43.2	28.8	15.3	48.6	53.2	41.4	1.8	13.5	58.6	21.6
China Beijing	110	44.5	36.4	15.5	50.9	29.1	9.1	61.8	31.8	6.4	23.6	45.5	21.8	4.5	51.8	40.9	10.0	5.5	83.6	59.1	37.3	1.8	7.3	64.5	26.4
China Shanghai	120	25.8	9.2	65.0	4.2	71.7	24.2	17.5	37.5	45.0	23.3	38.3	38.3	32.5	23.3	44.2	8.3	25.0	66.7	6.7	50.8	42.5	2.5	53.3	44.2
China Zhejiang	124	37.9	0.0	62.1	4.0	81.5	14.5	30.6	0.0	69.4	46.0	1.6	52.4	43.5	12.9	43.5	15.3	0.0	84.7	10.5	82.3	7.3	0.8	58.1	41.1
Colombia	100	24.0	18.0	58.0	37.0	50.0	13.0	41.0	9.0	50.0	37.0	11.0	51.0	36.0	2.0	62.0	57.0	14.0	29.0	35.0	34.0	31.0	24.0	36.0	40.0
Egypt	101	22.8	67.3	3.0	32.7	64.4	2.0	18.8	30.7	45.5	30.7	29.7	23.8	45.5	10.9	28.7	42.6	21.8	11.9	11.9	53.5	22.8	9.9	62.4	5.9
England	136	30.1	21.3	37.5	26.5	40.4	27.9	14.7	49.3	24.3	9.6	65.4	7.4	6.6	20.6	56.6	15.4	4.4	61.0	14.0	24.3	46.3	16.2	44.9	19.9
Fiji	100	48.0	23.0	26.0	82.0	9.0	9.0	40.0	23.0	37.0	37.0	19.0	40.0	58.0	5.0	32.0	61.0	9.0	27.0	49.0	27.0	20.0	64.0	22.0	5.0
Finland	107	30.8	46.7	22.4	52.3	41.1	6.5	30.8	57.0	12.1	71.0	28.0	0.9	41.1	24.3	34.6	43.9	17.8	38.3	29.9	56.1	14.0	4.7	50.5	44.9
France	106	18.9	5.7	73.6	10.4	21.7	59.4	14.2	29.2	54.7	11.3	29.2	53.8	20.8	8.5	68.9	2.8	12.3	78.3	6.6	17.0	72.6	12.3	20.8	52.8
Germany	88	48.9	14.8	35.2	6.8	62.5	30.7	51.1	9.1	39.8	35.2	28.4	36.4	5.7	21.6	67.0	13.6	9.1	77.3	20.5	46.6	33.0	0.0	21.6	78.4
Greece	100	32.0	16.0	50.0	35.0	34.0	30.0	31.0	26.0	42.0	48.0	30.0	22.0	46.0	16.0	38.0	48.0	8.0	43.0	76.0	14.0	9.0	5.0	21.0	73.0
Hong Kong	100	55.0	9.0	33.0	42.0	47.0	9.0	23.0	40.0	36.0	18.0	25.0	56.0	42.0	3.0	53.0	14.0	7.0	79.0	35.0	52.0	12.0	10.0	56.0	33.0
Israel	88	62.5	25.0	10.2	43.2	42.0	14.8	18.2	61.4	20.5	78.4	14.8	6.8	43.2	43.2	13.6	45.5	52.3	0.0	37.5	45.5	14.8	56.8	30.7	10.2
Japan	138	82.6	9.4	6.5	56.5	41.3	2.2	42.0	14.5	43.5	62.3	17.4	19.6	44.9	5.8	47.1	34.8	19.6	44.2	73.2	21.7	5.1	29.7	49.3	17.4
Mexico	102	24.5	6.9	66.7	42.2	42.2	13.7	20.6	20.6	56.9	37.3	22.5	36.3	52.9	7.8	36.3	58.8	5.9	33.3	30.4	42.2	25.5	18.6	52.9	26.5
Nigeria	55	23.6	32.7	40.0	38.2	47.3	9.1	38.2	23.6	30.9	23.6	23.6	40.0	34.5	25.5	40.0	49.1	21.8	21.8	20.0	54.5	21.8	27.3	36.4	10.9
Peru	108	42.6	20.4	36.1	64.8	33.3	0.9	38.9	16.7	41.7	57.4	11.1	21.3	63.9	10.2	18.5	64.8	2.8	22.2	30.6	58.3	8.3	33.3	44.4	14.8
Philippines	100	35.0	31.0	34.0	62.0	33.0	5.0	58.0	24.0	18.0	36.0	26.0	25.0	41.0	7.0	52.0	55.0	6.0	37.0	34.0	56.0	10.0	41.0	47.0	11.0
South Africa W	110	20.9	10.0	68.2	40.0	27.3	17.3	38.2	25.5	35.5	25.5	30.9	39.1	12.7	25.5	58.2	26.4	16.4	46.4	19.1	25.5	50.9	20.0	56.4	20.9
South Africa J	203	32.5	25.6	41.9	78.8	20.7	0.5	36.0	40.9	22.7	46.3	21.7	29.6	48.3	13.8	36.9	60.1	10.3	26.1	45.3	51.7	2.0	32.5	41.4	25.1
Spain	121	50.4	25.6	17.4	84.3	14.0	1.7	52.1	27.3	16.5	65.3	17.4	13.2	66.9	13.2	16.5	61.2	24.0	9.9	76.9	11.6	0.0	82.6	11.6	0.8

Sweden	145	38.6	18.6	40.7	33.8	30.3	33.8	40.0	22.8	36.6	38.6	19.3	40.0	17.2	29.0	50.3	33.8	3.4	57.9	41.4	35.9	19.3	21.4	29.0	44.1
Taiwan	110	13.6	58.2	25.5	16.4	44.5	30.0	5.5	24.5	68.2	15.5	38.2	45.5	5.5	10.9	83.6	8.2	50.0	40.9	18.2	49.1	30.0	7.3	36.4	56.4
Thailand	117	52.1	17.1	29.9	38.5	45.3	15.4	24.8	34.2	39.3	19.7	67.5	11.1	46.2	11.1	41.0	32.5	18.8	47.9	69.2	25.6	4.3	45.3	42.7	8.5
Turkey	119	63.9	17.6	18.5	46.2	48.7	5.0	45.4	18.5	36.1	58.0	25.2	16.8	81.5	4.2	14.3	34.5	9.2	56.3	51.3	34.5	14.3	34.5	26.1	39.5
United States	154	42.9	14.3	41.6	42.9	38.3	14.9	63.6	20.1	15.6	50.0	22.7	24.0	38.3	7.1	53.9	33.8	16.2	47.4	72.1	18.2	7.8	32.5	39.6	27.3

Note: N = Naive; M = Mixed; I = Informed; W= Western Cape. J = Johannesburg.

Table 2. The worldwide average of findings for each aspect of SI in 7th and 12th grade.

Aspect %	7th Grade ($n = 2634$)				12th Grade ($n = 3917$)			
	NA %	Naïve %	Mixed %	Informed %	NA %	Naïve %	Mixed %	Informed %
Starts with a question	5.5	43.9	29.9	20.7	2.8	40.2	21.3	35.6
Multiple methods	5.8	54.4	33.8	6.0	2.3	42.7	40.2	14.8
Same procedures may not yield same results	6.5	54.0	25.5	14.0	1.9	36.0	28.7	33.4
Procedures influence results	10.3	40.7	33.1	15.9	4.1	40.1	27.8	27.8
Conclusions must be consistent with data collected	6.4	39.7	20.6	33.3	3.4	40.4	15.8	40.4
Procedures are guided by the question asked	7.6	44.8	20.1	27.5	5.0	36.8	13.6	44.6
Data and evidence are not the same	9.0	48.5	32.1	10.4	4.3	40.1	37.6	18.0
Conclusions are developed from data and prior knowledge	9.9	41.3	37.9	10.9	5.3	26.2	40.8	27.7

Note: NA = No answer.

Australia

A national curriculum has been implemented in many Australian states and territories since 2011; however, the curriculum for post-compulsory secondary education is still governed by individual state authorities. A total of 91 students from two sites took part in the Australian study, comprising 28 male students and 63 female students. These students were deemed to be representative of other Grade 12 students in Australian schools in terms of their socioeconomic status, academic ability and cultural/ethnic backgrounds. Two rounds of coding were conducted by two researchers. Findings indicated that Australian Grade 12 students failed to express informed views of most aspects of scientific inquiry, with the majority of students expressing mixed views of six of the eight aspects. A consideration of these findings in conjunction with findings from the international study (Lederman et al., 2019), indicate that both Grade 7 and Grade 12 Australian students exhibit largely uninformed views of the nature of scientific inquiry; however, some positive improvements in student views are evident by the end of high school.

Austria

All three Austrian National high schools that were selected for this study (Grade 9-12) are based on the Competence Model for the Natural Sciences (Austrian science standards). This model consists of 15 dimensions of content (5 for each subject), 3 dimensions of requirements, and 3 dimensions of action, the latter including NOSI aspects such as planning and conducting an experiment as well as scientific reasoning. A total of 113 students from five urban public schools completed the questionnaire, most of them with a high socioeconomic background. All show a medium to high cognitive ability and a very good reading ability. The completed questionnaires were analysed and scored by two researchers, then 20% of the participants was interviewed. The results show that Austrian 12th grade students' knowledge about NOSI, although considered middle and high ability, is very heterogeneous. With several NOSI aspects, almost the same amount of informed as well as naïve responses were found. Results from questionnaires and interviews reflect the high variation of NOSI in Austrian classrooms: while some teachers integrate NOSI aspects in their lessons, the majority seldom offer the opportunity for personal NOSI experience or a reflection about it.

Brazil

In Brazil, the National High School Standards point out general guidelines for science education to promote research to understanding science, however, there are no direct orientations related to inquiry. A sample of 445 students from eight cities of the five regions of Brazil answered the questionnaire. The data were analysed by 10 researchers. The schools represent public and private education and half of them adopt some pedagogical proposal of investigation. The data demonstrate that scientific inquiry is poorly understood by Brazilian students, considering that 50% or more were classified as naïve in all aspects. The two aspects that most presented informed answers were *procedures are guided by the question* (18.7%) and a*ll investigations begin with a question* (13.9%). It is noted by the students' answers that the most understood idea is related to the aspects of which the questions begin and guide the investigative process. These informed results are derived from most of the students in schools that adopt some type of research activity in their curriculum, demonstrating that at least these activities result in some notion of inquiry as they understand that research is the search for answers to some

Bulgaria

The National Educational Standards prioritises NOSI aspects through activities in the science classroom. In this study, 105 students from three schools in the city of Plovdiv were selected to participate. As a way to represent the typical Bulgarian schools, students have different socioeconomic status, different cognitive abilities and interests. After the questionnaires were answered, they were scored by three researchers. Then a subsample of 20% of students were interviewed. The results show that about half of the tested Bulgarian students have a naïve or mixed understanding for all aspects of NOSI. For students it is difficult to understand some aspects of NOSI as well as to make practical applications of what they know. Although in the latest educational documents in Bulgaria special attention is paid to scientific education and NOSI, the topic of how to make a science research is not included in the curricula of Bulgarian school education. The results can be explained by the teaching-centred approach that unfortunately has an important place in a great number of schools in Bulgaria. Also, for a long period of time laboratory activities were few, but in the last five years, more and more attention has been paid to laboratory experiences.

Canada

In Canada, education is within provincial jurisdiction and the province oversees curriculum. The province of Ontario's Grade 11 and 12 Science Curriculum explicitly supports NOSI and outlines specific expectations for scientific investigations. Although the curriculum provides very clear examples of initiating, planning and performing investigations, it is not clear what data analysis and interpretation entails. In this study, 90

12th grade students from six high schools in Ontario, completed the questionnaire, and 20% were interviewed. Two researchers scored the questionnaires. In order to have a study population that represents the student diversity in Canadian schools, study participants were recruited from both public and Catholic schools. Findings show that most of the 12th grade students from Ontario, Canada who participated in the VASI study held informed and mixed understanding of NOSI. The students demonstrated an understanding of the aspects of NOSI related to initiating, planning and performing investigations, compared to those related to data analysis and interpretation. These results have implications for how the science curriculum can support NOSI in high schools. In this study, students performed better in those NOSI aspects in the curriculum that are supported by examples.

Chile

The national science curriculum for high school has an explicit section of learning objectives for scientific skills, but there is not an explicit mention for NOSI as content or a teaching methodology. A representative sample of 111 students from two public high schools located with a different socioeconomic status answered the questionnaires and 20% were interviewed. Two researchers analyzed and coded each questionnaire. The results varied according to NOSI aspects, although in half of the aspects they showed more naïve visions of NOSI. The most informed aspect was *procedures guided by a question* (48.6%). The more naïve answers were found in *data differ from evidence* (53.2% naïve, 1.8% informed) and *no single method* (55.9% naïve, 8.1% informed). Students explicitly admitted not knowing the difference between data and evidence. A possible explanation for results could be the differentiated high school curriculum, where 11th and 12th grades give the chance for students to choose science, language, math, arts or social sciences classes. Being in science classes usually means more laboratory sessions. Therefore, some aspects about the rationale for inquiry can be understood by some students, while others not. The 'only one scientific method' is still a powerful idea for 12th grade students regardless of their scientific practice experience.

Mainland China

With more than a decade of advocating inquiry in the national biology, physics and chemistry curriculum standards, high school science are taught as separate disciplines, and learned not only by lecture but also sometimes through inquiry activities. Doing scientific inquiry is also especially emphasised in the practice of science teaching. There were three regions of mainland China who took part in this study.

Beijing

In this study, samples came from a high school where students learn both the national compulsory curricula for a diploma and the international curricula so they can apply to universities all over the world. Grade 12 students ($n = 110$) answered the questionnaires, then 26 of them were interviewed. Two raters coded all data independently. More than half of students' ideas were naïve about the aspects: *data does not equal* *evidence*, *multiple methods* and *same procedures may not get the same results*, mixed about *explanations are developed from data and what is already known* and *conclusions consistent with data collected*, and informed about *procedures are guided by the question asked*. It seems that students held better ideas about the aspects of NOSI that are mentioned to some extent in national standards than those that are not addressed at all.

Shanghai

In this study, a representative sample of 120 students from three public schools was selected to participate. They answered the questionnaires and a sub-sample of 20% of students were interviewed. Two researchers scored the tests. The results showed that the majority of Shanghai students scored informed in half of the aspects of NOSI. The most informed aspects were *procedures are guided by the question asked* (66.7%) and *begins with a question* (65.0%). The aspect with a more mixed answer was *multiple methods* (71.67%) indicating the belief in one single method to do science. This lack of understanding of NOSI can be explained by the lack of emphasis on teaching the NOSI aspects, the teachers' perception that inquiry activities require more preparation time, and the teacher's understanding of inquiry.

Zhejiang

In this study, 124 students in grade 12 in Zhejiang were selected to participate. They answered the questionnaires and a sub-sample of 25% of students were interviewed, the tests were coded independently by six researchers. According to the statistics, the percentage of informed views was considerably higher than naïve views for most aspects. More than 50% of students were informed in three aspects, namely, the proportion of *procedures are guided by the question asked* (84.68%), *Same procedures, different results* (69.35%) and *begins with a question* (62.10%). For *multiple methods*, most students cannot explain this aspect with examples. The results can be partly explained by the importance of NOSI in science standards and implementation in scientific teaching practice. Students' ambiguous understandings of some specific aspects of NOSI show that professional training and guidance are needed to understand and carry out NOSI in the classroom.

Colombia

Two official documents guide the science teaching in the Colombian national curricula. The basic standards for science and environmental education clearly express that students should develop knowledge about science and process skills through experimental work. In this study, a representative sample of 100 students with different socioeconomic levels from a public school answered the test. Then, a sub-sample of 20% were interviewed. Four researchers analysed and scored the questionnaires. Overall, the results mostly exhibited informed answers in five of eight aspects of NOSI. The most informed aspects were *conclusions consistent with data collected* (62%) and *begins with a question* (58%). Instead, the most naïve aspects were *procedures are guided by the question asked* (57%) and the *same procedures may not get the same results* (41%). These results show that 50% of Colombian students are able to express informed views, indicating that this knowledge is still limited. One reason could be that there is no explicit mention to ‘understand’ scientific inquiry in the standards, so the aspects are not explicitly taught in Colombian classrooms.

Egypt

The Egyptian curriculum emphasises content coverage over practices and skills as it is test driven with an emphasis on grades and passing exams. Individual teachers have tried to shift to more student-centred approaches, but their efforts seem limited to provide opportunities for questioning, investigating, observing and collecting valid evidence. In this study, 101 students from public and private schools answered the questionnaires and three researchers used the coding system to score the responses. Results showed that responses were mainly ‘Mixed’ in four of the eight NOSI aspects. In three aspects, students showed mostly ‘Naïve’ responses. The highest aspect of NOSI with ‘Informed’ responses was for *the same procedures, different results* (45.5%) while the lowest ‘Informed’ response was *multiple methods* (2.0%). It is possible to deduce that students have some understanding of NOSI aspects; however, this seemed fragmented and inconsistent. Possible explanations relate to science teaching that is based on teacher-centred approaches with little opportunities for students’ hands-on activity, group-work or critical and creative thinking.

England

Scientific inquiry in Year 11 is taught as stressed in the national examination syllabi – the General Certificate of Secondary Education. All syllabi follow content specified by the Government Department for Education that includes the development of scientific thinking and experimental skills and strategies. A sample of 136 students representing a wide range in socioeconomic status from a state-funded secondary school in the South-West of England answered the questionnaire. Interviews showed no conflicting interpretations. Students showed the most informed aspects: *Procedures are guided by the question asked* (61.0%) and *conclusions consistent with data collected* (56.6%), and *data does not equal evidence* (46.3%). The results can be explained by the highly structured approach to teach science in UK schools and the repetitions of experiments to reach the reliability of their results. Finally, the idea that the different methods used by a scientist may affect results is understood by students. The understanding that different scientists may view these outcomes differently, is largely naive for this sample. The National Science Curriculum focuses on key features of ‘doing’ enquiry, so that students can answer relevant scientific questions. The following types of scientific enquiry are stressed in the curriculum: observing over time; pattern seeking; identifying, classifying and grouping; comparative and fair testing; and researching using secondary sources.

Fiji

All years of school education in Fiji are guided by the National Curriculum Framework which provides a clear direction about school curriculum. This document adopts a constructivist view of science education with a focus on process rather than content. While NOSI is recommended, lessons continue to be didactic. One hundred students of average academic ability representing the ethnic diversity, gender and socioeconomic background of Fiji, participated in this study. The questionnaires were scored by two researchers and a subgroup of 20 participants were interviewed. The results showed the majority of the participants held either naïve or mixed views about NOSI aspects. In particular, the majority showed a naïve understanding of scientific methods. To them individual process skills were considered as methods such as making a hypothesis or drawing conclusions. Further, experimentation and research were the only scientific methods known. The result reflects the lack of student experiences of NOSI and the need to examine the curriculum's emphasis and subsequent teacher readiness towards learning and teaching through NOSI.

Finland

According to the year 2003 curriculum, upper secondary science subjects should give students a picture of the living environment and the interaction between human beings and the environment, and to help them realise the significance of individual and collective responsibility based on scientific knowledge. The curriculum does not emphasise aims related to the 'nature of science' or 'nature of science inquiry' topics. There are only few concrete aims related to the learning of nature of science topics and almost no aims for learning the nature of science inquiry. However, there were several aims for learning inquiry skills. In this study, 107 students from five public upper secondary schools from three different cities were participating and representing different socioeconomic background families. After the questionnaires were answered, they were scored by two researchers. In general, the results indicated six aspects where students showed mixed answers and two aspects showed naive answers. The most informed aspects were *explanations are developed from data and what is already known* (44.9%) and *procedures are guided by the question asked* (38.3%), and *conclusions are consistent with data* (34.6%), however, these results are low compared with mixed and naive answers in the same aspects.

France

While mastering scientific inquiry is supposedly required by the curriculum for all French students, students choose a major at the end of their first year of High School (15–18 years old.). Only the selected students, who major in science, receive specific training until the end of their courses. This study involved 106 students from an urban city High School. The questionnaire was passed in the middle of June, just before the terminal exam (Baccalauréat). The questionnaires were then scored by two researchers. Most students (53–78%) fall into the 'informed' category for all the VASI aspects. Such good results may be explained by the combination of philosophy courses with an emphasis on the nature of science, traditionally a key feature of the last high school year in France, and of mandatory experimental practices in science courses. Generally, the VASI results appear to confirm the high selectivity of the French system, already established through the PISA test.

Germany

Though there are no national science education standards for grades 11 and 12, the curricula, in all federal states, do include an introduction to aspects of scientific work, that is, introducing students in biology, chemistry and physics as scientific disciplines. The sample ($n = 88$) stems from two academic track schools. Data were analysed by three researchers; pairs of two coded students' responses. Disagreed ratings were discussed by all three researchers until consensus was reached. Students were most informed regarding the following NOSI aspects: *Conclusions are consistent with data collected* (78.4%), *explanations are developed from data and what is already known* (78.4%), and *procedures are guided by the question asked* (77.3%). This may be due to a focus of science lessons on planning and performing scientific investigations, and on analyzing data. The most naïve responses were expressed regarding *Same procedures, different results* (51.1%) and *begins with a question* (48.9%). Science instruction seems to seldom exemplify the subjective nature of science and rather emphasises the objectivity and exactness of scientific investigations.

Greece

In Greece, there is one official curriculum and one textbook that determine science teaching. Accomplishment of inquiry skills is included in official documents, but in most activities, students perform inquiries of the first level to confirm a law or a phenomenon, since the system is more academic with lectures. Twelfth grade is a preparation year for the National Exams to enter university. In this study, 100 students participated from five high schools, three of which are 'Experimental', linked to universities and where students are admitted after an entrance examination. These schools represent most regions of the country and their students have similar and above average performance. All students attended Advanced Science and Math courses. Ten researchers scored the questionnaires with average inter-rater reliability of 88.3%. Results showed that students are knowledgeable about the following aspects; starting and guiding research, explanations are developed from data and what is already known, but they give naïve answers in all the aspects related to practical work and the procedure of a research. This result reflects the theoretical/academic emphasis of the curriculum and the lack of experimental work and higher levels of inquiry in science classrooms.

Hong Kong

NOSI is emphasised in the science curricula for senior secondary students. It is largely regarded as a skill, except in the Biology curriculum where an understanding of the nature of NOSI is explicitly stated. One hundred students in their first year of study at a local university participated in this project. They had just completed their six-year study at local secondary schools. All data were coded by two researchers. Participants performed the best on 'Procedures are guided by the question asked' aspect and their understandings of the followings aspects were found to be problematic: (1) b*egins with a question*: Participants tended to believe that scientific investigations can begin with any questions; (2) *data does not equal evidence*: A misconception was that data were limited to numbers and statistics; (3) *multiple methods*: Participants failed to identify ways other than laboratory experiments as a means of scientific investigation. This is consistent with their secondary schooling experience in science on the emphasis of conducting experiments for scientific investigation.

Israel

Students in Israel are exposed to scientific journals' short articles, which are revised for them in a less scientific language. Using animations and interactive experiments is also a popular and recommended strategy in teaching and learning the scientific disciplines. Also, a major emphasis is put on inquiry-type experiments and inquiry-type experiments are mandatory in the chemistry, biology and physics laboratories. A heterogeneous population of 88 Israeli students with different economic backgrounds from two high schools answered the questionnaires. A sub-sample of 20% of students were interviewed. The tests were scored by two researchers. The results show mostly naïve answers in five of eight aspects. The most informed aspects were *same procedure, different results* (20%) and *data not equal to evidence* (45.5%). It is suggested, that if students are not taught in an explicit way about scientific inquiry, they might not be acquainted with its process, nor differentiate between the meaning of related concepts, e.g. data versus evidence.

Japan

The main aim of science education in Japan is to understand scientific knowledge and to enable students to perform investigations scientifically. Overall, objectives are to enable students to take an active interest in natural things and phenomena, and to carry out observations and experiments. For that reason, students learn scientific knowledge through a lecture and sometimes do investigations. For this study, a sample of 138 students with similar socioeconomic background from three schools located in Kanagawa and Saitama prefectures answered the questionnaire and 20% were interviewed. The questionnaires were analyzed by two researchers. The results show few students who are evaluated as 'Informed' in almost all aspects of NOSI. The most informed aspects were *procedures are guided by the question asked* (44.2%) and *conclusions consistent with data collected* (47.1%). However, those aspects have similar percentages of naïve and mixed answers respectively. The results can be explained because Japanese students do not have the opportunity to learn about scientific inquiry explicitly since national standards are not imposed to do so and also teachers do not teach NOSI.

Mexico

Recent reforms in México's education system have provided a Common Curricular Framework for the upper secondary level. The standards of scientific knowledge are expressed in the updated curriculum, as well as in the study programs with emphasis on the scientific inquiry skills throughout experimental activities and projects. A sample of 102 students with diverse socioeconomic status from a public high school affiliated to the National Autonomous University of Mexico (UNAM) answered the questionnaires and 20% were interviewed. The students belong to a preparatory course with emphasis on disciplinary knowledge and preparation for university careers. Three researchers scored the questionnaires. In general, the results show that Mexican students show more naïve and mixed answers for the aspects. The most informed aspects were *begin with a question* (66.3%) and *same procedures may not get the same results* (56.9%). It was clear during the analysis of the questionnaires that students ended up using their prior knowledge in certain topics such as, photosynthesis in question six, to answer the question and did not use the data that was presented in the questionnaire.

Nigeria

Recently, there has been a review of the Universal Basic Education Curriculum by the Nigerian Education Research and Development Council. There were 55 participants drawn for this study in a convenient sample across five private schools in the middle belt geopolitical zone of the country. Findings suggest that the students who participated in this study very well realise the role of procedures in the results that emerged from scientific inquiry, but they are naïve as to the details of how procedures are set up to influence results. It seems also counter-intuitive to them that as impactful as procedures are to results of scientific inquiry, same procedures may not get the same results. This dilemma is interpretable in the light of their mixed understanding of the enormous role of theory in scientific explanations. Similarly, the students appreciate the role of questions but are at a loss as to how questions frame procedures in scientific inquiry. These findings may be indicative of or suggest the need to teach NOSI as content.

Peru

The Peruvian national curricula emphasises the development of competences in the 'science and technology' subject. The curriculum has a strong focus on scientific inquiry, scientific literacy, and technology to contribute in the development of informed citizens that can make decisions about themselves and the society. A representative sample of 108 students from public schools answered the questionnaire and 20% were interviewed. Peruvian students showed mostly naive views in five of eight aspects of NOSI. The most informed aspect was *same procedure, different results* (41.7%). Instead, the aspect *begin with a question* also shows informed views (36.1%), however, this results is low compared with the naïve views in the same aspect (42.6%). These results can be explained by the lack of emphasis related with 'understanding' scientific inquiry versus 'doing' inquiry in the classroom. Also, Peruvian teachers are learning new teaching strategies about how to incorporate the new science curriculum into the classroom.

Philippines

All public schools in the Philippines use: K-12 Curriculum Guide: Science to teach science. The curriculum guide aims to promote learner-centred, inquiry-based instruction that uses evidence to explain scientific knowledge. In this study, 100 grade-12 students completed the survey and 20 students were interviewed; and three researchers analyzed the data. Overall, participants largely held naïve to transitional views in the NOSI aspects. For *multiple methods*, 62% of participants held naïve views, potentially due to an overemphasis on experimentation in the curriculum. Yet, 52% of participants had informed views of *conclusions consistent with data collection*, the highest percentage across all NOSI aspects. This is a positive outcome, as assessments and instructional materials continue to overemphasise content breadth and fact accumulation. As the Philippine educational system follows a top-down structure, the curriculum and standards likely play a major role in shaping instruction.

South Africa

The National Curriculum Statement prompts teachers to use inquiry-based approaches to teaching science in all grades, including Grade 12. The teaching and learning of science as inquiry is strongly emphasised within the South African Curriculum and Assessment Policy Statement. This progressive curriculum is, however, poorly implemented in schools and even when enacted, the focus is mainly on confirmatory inquiry and the acquisition of science process skills. There were two regions in South Africa who took part in this study.

Western Cape

The sample was drawn from a public high school in a low-income area. The school receives funding from a private trust, supporting science teaching through well-equipped science teaching laboratories. From this school, 110 Grade 12 learners volunteered to participate in the VASI study. A team of three researchers analyzed, scored and discussed answers to establish 80% agreement. For interviews, 20% of students were selected according to differences in their outcomes in the VASI. The results showed that more than half of the sample had informed views in three aspects of NOSI namely, *begins with a question* (68%), *conclusions consistent with data collected* (58%) and *data does not equal evidence* (51%). The results can be understood in terms of the emphasis placed by the curriculum and textbooks on asking investigative questions, collecting data and making conclusions. It is, therefore, plausible that teachers also emphasise these ideas in classrooms throughout the school career, thereby developing learners' understanding of these aspects of inquiry.

Johannesburg

In this study, 203 students from six representative schools completed the questionnaire and semi-structured interviews followed thereafter with 20% of the participants and two researchers analyzed and coded each questionnaire. Findings revealed that the majority of the students lacked informed understanding about most aspects of scientific inquiry, with the most informed understanding registered at 41.9% for the aspect *begins with a question*. From semi-structured interviews learners indicated that they barely did practical tasks and even when they did, results and explanations had to confirm learnt science concepts. It was concluded that more needed to be done intentionally and consistently teaching learners aspects of scientific inquiry. It was further noted that acquisition of informed understandings about scientific inquiry is not obtained accidentally, but rather has to be taught, with explicit instructions and critical reflections.

Spain

Three official documents guide teaching in Spain but none of the documents promote NOSI in science classrooms explicitly. In the classroom few opportunities are left to the exploration of phenomena and investigation, since it performs teaching as factual and the reproductive of concepts. In this study, a representative sample of 121 students with different economic backgrounds from three public schools answered the questionnaire and a sub-sample of 20% of students were interviewed. Questionnaires were scored by two researchers. In general, Spanish students show a naive view of over 50% for all aspects of NOSI. After analyzing the responses of Spanish students, it can be seen that they can conceptualise some aspects of NOSI, but they do not understand its meaning or know how to develop them in real situations. This result emphasises the need to carry out activities associated with solving real problems to promote understanding and practice of scientific research in science classrooms.

Sweden

In the Natural Science Program students study Physics, Chemistry and Biology. The syllabus for each subject contains a specific set of educational goals particularly focused on the nature of science and scientific inquiry. Six schools with a total of 145 students participated. The schools were chosen from the 41 schools in the Stockholm area that have the Natural Science Program. The six schools represent a cross-section of students in Sweden based on the schools' socioeconomic index of the school provided by the municipality. Only 4 students (3%) could be interviewed due to some practical issues beyond the researchers' control. On average, we have 40% of informed aspects in our students' understanding of inquiry. The highest level of informed answers is found in the aspect that *the same procedures may not yield the same results*. This may be related to the rather strong tradition of analyzing practical work by qualitatively estimating sources of errors. The lowest level of informed answers is for the aspect *data versus evidence*. This is not strange as is not emphasised in the teaching tradition or in common textbooks, and that these terms are somewhat ambiguous to translate and have other connotations besides scientific in a Swedish context (Lederman et al., 2019).

Taiwan

In Taiwan, the science curriculum for high school students, at the time this investigation was conducted, is based on the curriculum guidelines enacted in 2013. The specific term 'scientific inquiry' is only present in the Biology curriculum goals but not clearly defined. This investigation recruited 110 grade 12 students (male 47, female 63) from three high schools across different regions. Students' responses to the questionnaire were coded and 22 students were selected for interviews by three researchers. The results show that Taiwanese 12th grade students hold mixed views in four aspects of NOSI and informed views for the other four. The highest percentage of informed views happened to *conclusions consistent with data collected* (83.6%) because students were good at responding to such a question with logical and structured answers and *Same procedures may not get the same results* (68.2%). For all of the NOSI aspects, less than 20% students' views were coded under the naïve category. These sampled students may outperform their counterparts because all of them chose the science track and their teachers have been proactive in reforming the science curriculum. Teachers' views of NOSI and implementation of inquiry-based curriculum may have certain impacts on students' understanding of NOSI, which needs further exploration.

Thailand

NOSI has been the central focus in the science education reforms in Thailand pre-college schooling and inquiry-based pedagogies have served as the benchmark for school science. A total of 117 12th grade students from a public secondary school were involved in this study. All student responses from the VASI questionnaire were scored by three researchers, and a sub-sample of 20% of the students were interviewed. The results show that most of them held naïve or mixed views of six of the eight aspects of NOSI examined in this study. For the most informed aspect, 47.86% and 41.03% of students exhibited informed views on *procedures are guided by the question asked* and *conclusions consistent with data collected*. The most mixed and naïve aspects of NOSI were 67.52% and 69.23% on *Procedures influence results* and *data does not equal evidence*, respectively. In conclusion, it seems Thai students failed to express a qualified view of NOSI. This implies that the facilitation of students' understanding of NOSI by inquiry approach is not done in an explicit way because the absence of a particular learning experience addressing NOSI.

Turkey

Biology, chemistry and physics are taught as separate subjects in secondary education in Turkey. Teaching and learning about scientific inquiry are valued in the curricula of all secondary science subjects. Indeed, there are many direct and indirect references to the nature of scientific inquiry in the learning objectives. The study group consisted of 119 12th grade students from a public school in Istanbul. The school was in a low-socioeconomic status region of Istanbul, which represented a large portion of Turkey's population. Two raters participated scoring and evaluating the questionnaires. Findings showed that most of the students were in the naive category with regard to almost all aspects of NOSI. Students had especially naive understandings about some aspects of NOSI such as conclusions consistent with data collected (81.5%), begins with a question (63.87%) and, procedures influence results (57.98%). Despite the fact that the secondary science curricula put an emphasis on learning about the nature of scientific inquiry, these results indicate that this emphasis seems to have not permeated science classrooms in a way to improve students' understandings of NOSI.

Table 3. Chi squares per each aspect in each category comparing 7th and 12th grade.

		Naive		Mixed		Informed	
Aspect	df	χ^2	p	χ^2	p	χ^2	p
Starts with a question	1	44.820	.000	2.883	.090	425.768	.000
Multiple methods	1	12.075	.001	212.150	.000	266.557	.000
Same procedures may not yield same results	1	.090	.764	116.036	.000	530.262	.000
Procedures influence results	1	77.646	.000	24.719	.000	341.606	.000
Conclusions must be consistent with data collected	1	96.817	.000	30.994	.000	152.747	.000
Procedures are guided by the question asked	1	15.394	.000	.382	.536	471.242	.000
Data and evidence are not the same	1	19.876	.000	189.233	.000	212.374	.000
Explanations are developed from data and previous knowledge	1	4.295	.038	148.454	.000	483.137	.000

Note: p value significant at the $p < .05$ level.

United States

In the US, the science standards since 2000 have included the teaching of NOSI. The most recent iteration distinguishes between the abilities to do inquiry and knowledge about scientific inquiry and this distinction continues to be evident in the NGSS (NGSS Lead States, 2013). The sample in the US consisted of 154 students from three areas in the US (one in East area and two in Midwest urban areas). This sample was assembled to control and provide a representative sample for socioeconomic and ethnic diversity that is present in the US. Students in this sample had a significantly low understanding of two aspects; *Data is not the same as evidence* (72%) and *same procedures may not yield the same results* (64%). This may be because when students do labs, they are often very prescriptive and do not leave the option for an alternating result. The aspects with the highest levels of understanding were; *procedures guided by the question asked* (47%) and *conclusions are consistent with data collected* (54%). Higher levels of understanding for these two aspects also relate to the 'cookbook' labs that are often conducted in US schools where students use their data to answer the question asked.

Is any progress being made?

As mentioned before, it would be interesting to see if the results here are any different than those documented in the previous study by Lederman et al. (2019) with seventh grade students. In short, although this study is not in any way a longitudinal study stemming from the same students in prior studies. It is a cross-sectional follow-up study because there is still interest if students seem to be more aware of NOSI after completing their secondary school education. Thus, a Chi-Square analysis was completed comparing the aggregated data for each NOSI aspect for each category (naive, mixed and informed) between grades seven and 12. It is recognised that this approach led to a set of 24 chi-square tests (aggregated by NOSI aspect). However, given the descriptive and exploratory nature of this investigation, the increased error rate is justified. The results of the statistical analyses are reported below (Table 3).

Conclusions

With few exceptions, high school students were more informed about each of the aspects of NOSI than seventh grade students. Again, it must be emphasised that the students from the grade seven sample (Lederman et al., 2019) are not the same as the students from the grade 12 sample reported here. Although, the counties/regions included in the seventh grade studies were also included in this study of 12th grade students (with the exception of New Zealand). It is generally understood and intuitive that high school students should have an improved understanding of NOSI as they progress from seventh grade. For example, they are much better versed in science content and their cognitive development is more sophisticated than seventh graders, among other factors. Thus, the findings comparing the understandings of grade seven and grade 12 students are expected and welcomed. On the other hand, the frequencies of informed understandings for the aspects of NOSI are all below 45%. Naturally, there are isolated exceptions if one carefully reads the results by country/region in Table 1. However, overall, the worldwide understandings are below 45% for each NOSI aspect. Again, this consistency belies the variability in sample sizes and abilities of students across countries/regions. As discussed previously, the understandings of NOSI assessed in this study are generally expected outcomes for students graduating high school. Consequently, the results related to grade 12 students must be considered disappointing. Then again, given the reports of how science is taught from the research teams in each country/region the results are not surprising.

Implications

It seems clear, worldwide, that science is often taught by lecture or teacher-centred classrooms. Of the 32 countries/regions in this study over half of the sample reported the science teaching in these classrooms was teacher-centred lecture-based experiences with very few to no laboratory investigations. These observations are similar to the previous worldwide grade seven VASI study (Lederman et al., 2019). When students do engage in investigations, there is little reflection on what was done and why. It is clear that no matter where students live worldwide NOSI understandings are not developed at the level expected by the end of formal schooling. It is important to note that no statistical comparisons were made among countries/regions as the purpose here was just to get a baseline of high school students' understandings as they compare to what has been documented for grade seven students. Although readers may be tempted to compare the results from their country/region with others, informal or statistical comparisons across countries/regions would be inappropriate given the previously mentioned contextual differences across locations. It is also important to note that some countries/regions may be more interested in some aspects of NOSI than others. Therefore, the findings here may be more compelling for policy changes in some areas as opposed to others.

High school is the end of many, if not most, students' formal science education. It is critical that students' understandings of inquiry are fully developed by this point in their academic career to be participating members of society. The prior study (Lederman et al., 2019) focusing on grade seven students also showed very little understanding of NOSI internationally. Although, research has found that very young children (grade one and above) are able to adequately understand several aspects of scientific inquiry; s*cience begins with a question, there is no single scientific method and conclusions are based on data gathered and what is already known* (Lederman, 2012). Students should at the very least have informed views of at least some of the aforementioned aspects by completing high school.

The reader may be asking, ‘Is it really important for students to understand NOSI given the relative importance of foundational science concepts?’ There is no more relevant defense of the importance of understanding NOSI than the current international Covid-19 pandemic and how it is perceived by the public, as well as how information is presented to the public by those in authority. Most notably would be understandings about how investigations are designed and how data are interpreted by different individuals. That said, what needs to change the situation documented by the international data collected in this investigation?

There are several clear implications for the results presented here. First, policy makers must consider what understandings are considered important for their pre-college students and then consider approaches to alleviate the problem. Again, it is recognised that not all countries/regions may be strongly interested in students understanding all aspects of NOSI. Once decisions are made, teacher professional development and teacher education programs must be revised to integrate existing research (Szteinberg et al., 2014) on how to best facilitate teachers’ and students’ understandings of NOSI and teachers’ ability to teach NOSI. Understanding aspects of NOSI is a critical component of scientific literacy (Showalter, 1974) and it is critical knowledge that consumers of science will use throughout their lifetime. Consistent with anything else we want students to learn, if you want students to learn, it must be taught. ‘Taught’ does not mean a lecture, but rather engaging students in activities that facilitate their critical analysis of the science they are learning and how the science was developed.

A follow-up study is currently underway to assess elementary students (grades three and four) in the same locations to see what students’ initial understandings of scientific inquiry. To accommodate reading levels and developmental appropriateness, a revised version of the VASI has been developed with established validity and reliability. It is anticipated that the combination of the three international studies will provide a reasonable baseline for students’ understandings of NOSI during their pre-college education.

Limitations

Some may be concerned about the variability in the sample across countries/regions. Although the results here are robust regardless of the variability, pursuing comparisons across the traditional educational levels of ‘low, middle, and high’ may provide additional valuable information. Although probably most appropriate for smaller-scale studies (e.g. single countries/sites), it would be useful to focus systematically on actual classroom instruction. Such a focus was just not possible in an investigation of this magnitude. Finally, the purpose of the interviews was primarily to further document the validity of the VASI. However, gathering more focused interview data may provide additional insight into student thinking.

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