International Collaborative Investigation of Beginning Seventh Grade Students' Understandings of Scientific Inquiry

Abstract

Although understandings of scientific inquiry (as opposed to conducting inquiry) is included in science education reform documents around the world, little is known about what students have learned about inquiry during their elementary school years. This is partially due to the lack of any assessment instrument to measure understandings about scientific inquiry. However, a valid and reliable assessment has recently been developed and published, Views About Scientific Inquiry (VASI) (Lederman J. et. al., 2014). The purpose of this large scale international project was to collect the first baseline data on what beginning middle school students have learned during their elementary school years. Eighteen countries/regions spanning six continents including 2,634 students participated in the study. The participating countries/regions were: Australia, Brazil, Chile, China, Egypt, England, Finland, France, Germany, Israel, New Zealand, Nigeria, South Africa, Spain, Sweden, United States, Taiwan, and Turkey. In many countries, science is not formally taught until middle school, which is the rationale for choosing seventh grade students for this investigation. This baseline data will simultaneously provide information on what, if anything, students learn about inquiry in elementary school, as well as their beginning knowledge as they enter secondary school. It is important to note that collecting data from each of the 300+ countries globally was not humanly possible, and it was also 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. The results overwhelmingly show that students around the world in grade seven have very little understandings of scientific inquiry. Some countries do show some understandings in certain aspects but the overall picture of understandings of scientific inquiry is not what is hoped for after completing six years of elementary education in any country.

Keywords: scientific inquiry, international, literacy

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Introduction

Scientific inquiry (SI) has been a perennial focus of science education for the past century and it generally refers to the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge (Lederman, 2009). Recent reform documents have emphasized that students should develop the abilities necessary to do inquiry as well as have an understanding about inquiry (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], 2011). The National Science Education Standards (NRC, 2000) were explicit in their differentiation between the abilities to do inquiry and knowledge about SI. This distinction also continues to be evident in the Next Generation Science Standards (NGSS; Achieve, Inc., 2013). Similar distinctions are becoming more prominent in reform documents throughout the world. Quite simply, it seems logical that students will improve their ability to do inquiry if they have an understanding about what they are doing, and this knowledge combined with knowledge of science will enable students to make more informed decisions about scientifically based personal and societal decisions.

Research indicates that, much like the research on understandings of Nature of Science (NOS), neither teachers nor students typically hold informed views of SI (Lederman & Lederman, 2004; Schwartz et al., 2002). The research base for SI is markedly smaller than that for NOS. This small research base is partly due to both the conflation of NOS and SI and the lack of a readily available, or frequently utilized, instrument similar in nature to the various forms of the Views of Nature of Science questionnaires (VNOS; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Now with the development of the VASI the research base for SI can begin to grow.

While SI is inextricably linked with NOS, what is notable is the lack of a robust research base centered on students' understandings about inquiry. What is evident is the preponderance of research focused on the doing of inquiry, which oftentimes is assumed to imply an understanding of inquiry. The belief that doing inquiry is a sufficient condition for developing understandings about SI, unfortunately, is a misconception. (e.g., Wong & Hodson, 2009, 2010).

The intent of this collaborative project was to report on students' understandings of SI across the globe with a valid and reliable assessment tool is available; we can begin to see what students of the same grade levels know about SI in various countries/regions. The purpose is not to focus on comparisons across countries (especially since instruction, curricula, and cultures vary widely across nations), but rather to develop a baseline of understandings worldwide.

Why Should Students Understand Scientific Inquiry 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. SI is this process. The NSES content standards for Science as Inquiry for grades K-12 advocated the merit of students developing (a) the abilities necessary to do inquiry and (b) understandings about scientific inquiry (NRC, 2000). The "doing" of scientific inquiry is emphasized in the NGSS standards, within the category of "Practices". The NGSS expects teachers to have students; ask questions, planning and carrying out investigations and constructing explanations. Thus in the United States, teachers are encouraged to engage their students in conducting science investigations in their classrooms. But, the explicit teaching of understandings about Scientific Inquiry is missing from the NGSS. Although conducting inquiry, or the process skills of science, 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 SI, and for that matter NOS, have been called into question by a growing body of research (e.g., Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 2000; Lederman, Bartels, Liu, & Jimenez, 2013; Lederman & Lederman, 2004; Schwartz et al., 2002; Schwartz, Lederman, & Crawford, 2004). Therefore, it is important to identify and explicitly teach the aspects of SI that can serve, in the end, to develop informed views of SI. And, of course, the major endpoint desired is the development of a scientifically literate citizenry. It is important to note that "explicit' does not mean lecture or teacher centered instruction, as misunderstood by some researchers (Duschl & Grandy, 2012). Explicit/reflective instruction engages students in reflections upon what they did in an investigation and the implications this has for how scientists do their work and the knowledge that is produced.

The aspects of SI that follow are not only deemed appropriate in the context of K-12 classrooms, but can also be appropriately applied to college level students. Specifically, students should develop an informed understanding of the following Knowledge of Scientific Inquiry (SI) aspects: (a) scientific investigations all begin with a question and do not necessarily test a hypothesis; (b) there is no single set or sequence of steps followed in all investigations (i.e. there is no single scientific method); (c) inquiry procedures are guided by the question asked; (d) all scientists performing the same procedures may not get the same results; (e) inquiry procedures can influence results; (f) research conclusions must be consistent with the data collected; (g) scientific data are not the same as scientific evidence; and that (h) explanations are developed from a combination of collected data and what is already known. An elaboration of each SI aspect follows.

Scientific Investigations all begin with a Question and do not Necessarily Test a Hypothesis.

"Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world" (NRC, 2000). In order for scientific investigations to occur there has to be a question asked about the world and how it works. Unlike what is prescribed by The Scientific Method, students do not have to state a hypothesis before beginning an investigation. Traditional experimental designs typically include a formally stated hypothesis, but this is not necessary or typical of other designs (e.g. descriptive and correlational).

There is No Single Set or Sequence of Steps Followed in All Investigations.

Even when not explicitly communicated, school science often looks like the scientific method because of an overreliance on experimental design. Clearly, there are other ways that scientists perform investigations such as observing natural phenomena. The entire field of astronomy primarily relies on ways of gathering data, drawing inferences, and developing scientific knowledge that do not follow the "scientific method". Most often descriptive and correlational research methodologies are employed to gather data in this field. Students need to develop not only an understanding of the variety of research methodologies employed both across and within the domains of science, but that, in general, "scientist[s] use different kinds of investigations depending on the questions they are trying to answer" (NRC, 2000, pg. 20).

Inquiry Procedures are Guided by the Question Asked.

While scientists may design different procedures to answer the same question, these invariably need to be capable of answering the question proposed. If an astronomer sought to investigate the relationship between the age of a star and its luminosity, an experimental design would obviously be untenable, as he or she would be hard-pressed to conduct a "fair test" (i.e., manipulate variables). The procedures implied by typical experimental design clearly are not consistent with the question being investigated, as the researcher seeks to explicate the relationship among variables (i.e., correlational research). Similar to the aforementioned aspect of SI, students need to understand the necessity of this alignment between research question and method, in that the former drives and ultimately determines the latter. In general, students should understand that the question determines the approach, with the approaches differing both within and between scientific disciplines and fields (Lederman, Antink, & Bartos, 2012).

All Scientists Performing the Same Procedures May Not Get the Same Results.

Students need to understand that "scientific data does not stand by itself, but can be variously interpreted" (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003, p. 708). As such, scientists who ask similar questions and follow similar procedures may reach different conclusions, owing in part to their theoretical commitments, what scientists consider as evidence and they classify anomalous data also influence the results of a scientific investigation. Because of this, scientists who examine the same data may justifiably come to different conclusions. While the history of science is replete with examples of this, the use of similar data by evolutionary biologists to support their specific conclusions is a case in point. For example, a researcher operating from a Darwinian framework might focus his/her efforts on the location of transitional species. By contrast, from a punctuated equilibrist perspective transitional species would not be expected nor would what a Darwinian considered a transitional species be considered as such (Gould & Eldridge, 1977).

Inquiry Procedures Can Influence Results.

The procedure selected for a scientific investigation invariably influences its outcome. The operationalization of variables, the methods of data collection, and how variables will be measured and analyzed all influence the conclusions reached by the researcher. For instance, a common investigation in high school biology class examines the root cells of a plant to determine which stage of mitosis the cells are in. How the students sample the root determines what type of data they collect, therefore affecting the conclusions they may reach.

Research Conclusions must be Consistent with the Data Collected.

Each research conclusion must be supported by data. Students need to understand that the strength of a scientist's claim is a function of the preponderance of data that supports it. The validity of the claims is further strengthened by the alignment of the research method with the research question. It follows as well then, that claims must be reflected in the data collected. Scientific knowledge is empirically based, thus any explanations for the phenomena explored in investigations are anchored by the data that facilitates scientists' development of those explanations. Consider the relatively unusual case of pharmaceuticals whose clinical trial data, emerging after their approval, exhibit questionable links to more serious side effects than reported. Although the safety claims about such medicines may be supported to an extent by clinical studies, trends in the data that are suggestive of serious concerns may go without interpretation. The conclusions in these situations are inconsistent with the data and such inconsistencies in these types of cases have serious implications for consumers.

Scientific Data Are Not the Same as Scientific Evidence.

Data and evidence serve different purposes in a scientific investigation. Data are observations gathered by the scientist during the course of the investigation, and they can take various forms (e.g. numbers, descriptions, photographs, audio, physical samples, etc.) Evidence, by contrast, is a product of data analysis procedures and subsequent interpretation, and is directly tied to a specific question and a related claim. Observations of the orbit of Mars around the sun, in and of themselves, are, simply put, an example of data. When these observations are made in conjunction with an attempt to determine the validity of Einstein's General Theory of Relativity, they constitute evidence in support of, or in opposition to, this claim.

Explanations are Developed from a Combination of Collected Data and What is Already Known.

Investigations are guided by current knowledge. Conclusions, while derived from empirical data, are additionally informed by previous investigations and accepted scientific knowledge. Scientists need to recognize when conclusions differ from accepted scientific knowledge and determine how findings must be interpreted given what is already understood. Consider when paleontologists unearth dinosaur bones, these bones are not found in a perfect skeleton, scientists must use what they already know about skeletons in conjunction with the data (the newly unearthed bones) to construct the skeleton.

Statement of the Problem

Although the teaching of scientific inquiry is valued around the world, there has never been a worldwide assessment of what students actually know about scientific inquiry. This study sought to examine grade seven students' understandings, at the beginning of the school year, of SI in various countries worldwide. This baseline study gives us data on what, if anything, students learn about inquiry in elementary school, as well as their beginning SI knowledge as they enter secondary school. It provides the global science education community a starting point from which instructional, curricula, and policy decisions can be made.

Method

Sample

The sample was taken from every continent around the world, with the exception of Antarctica. The research sites (from 18 countries) were; Australia (n=108), Brazil (n= 169), Chile (n=142), Mainland China (n=378), Egypt (n=109), England (=103), Finland (n=149), France (n=109), Germany (n=96), Israel (n=92), New Zealand (n=87), Nigeria (n=102), South Africa (n=106), Spain (n=159), Sweden (n=126), Taiwan (n=167), Turkey (n=268); and the United States (n=164). The total sample size of grade seven students was 2,634 students. The students 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. The students were selected for this study by the contact people for that country. The contact researchers from each region/country determined which schools represented their regions based on the aforementioned criteria. The contact researchers selected were admittedly a sample of convenience. However, care was taken to select sites that reasonably "covered" each continent and no sites were selected in which the contact researchers stated that understandings of inquiry were not emphasized in their existing standards. There were a total of 18 primary contact people participating in this study, one contact person for each country/region, who almost always worked with a team of colleagues. Each site had one city with the exception of South Africa, Turkey, and the U.S. which had two sites each and China which had three sites. In short, the contact people across the six continents were responsible for language translation/back translation to maintain VASI validity when a language other than English was used, selection of a representative sample, data collection (including paper and pencil assessments and individual interviews), completion of training in the coding/scoring of the VASI, data analysis, and the writing of location specific aspects of the results. It is important to note that this ambitious investigation did not require the procurement of any external funds or grants.

Translation and Back Translation Process

In order to have a valid VASI questionnaire in a language different from the original English version, the researchers in each country/region translated the English version into the local language. One researcher in each country was responsible for doing the translations. The translated version of the VASI was then translated back into English by another member of the local team who had proficiency in reading and writing English. The back translated version was evaluated and compared with the original VASI questionnaire by one of the authors of the instrument in order to check if this new version maintained the same meanings as the original version. In some cases, it was necessary to contact the local teams to clarify some words used in the new local version of the VASI to double check if those words maintained the same meaning or were able to capture the answers in the same way as the original questionnaire. For example, when working on the back translation between the Swedish version of the VASI and the English version a discussion took place about the word "evidence" in Swedish this word translates into "proof" which has a different meaning in the U.S. Even in countries where English was the official language, researchers had to use some alternative words according to the local context in order to have a valid VASI questionnaire. For instance, the VASI version for U.S., England and Australia had to adjust words and phrases to reflect local vernacular to better match the meaning of the original questions. Similarly, the Spanish versions for Spain and Chile are different from each other. Only after the process of translation and back translation, was each team able to administer the questionnaires in each country/region.

Training Session for Scoring

The selection and training of the contact people for this study was completed by the U.S. researchers. This research began with an initial meeting at the European Science Education Research (ESERA) meeting. The initial timeline of the study was determined when the personnel at each research site was ready. Individual meetings were arranged and conducted via Skype between each site and the primary U.S. site. Depending on the research team there were two to three meetings. The first meeting involved learning to administer and score the VASI. After the administration of the VASI in each country/region, each site was required to send four or five completed VASI questionnaires from their sample. The responses were translated into English by each local team. Then, each questionnaire was independently scored by a group of four to five researchers from the U.S. team. Once the questionnaires were scored, a second meeting with the international local team was scheduled in order to explain how the questionnaires were scored and how the questions targeted the aspects of scientific inquiry. During this meeting, each local team discussed the quality of the answers, scoring, reliability and inter rater agreement. In a third meeting, each team scored a new set of questionnaires for themselves and then compared their scores with the U.S. team. This meeting allowed the local teams to "calibrate" the scoring process in order to get 80% or greater inter rater reliability. If additional meetings were needed they were scheduled on a case by case basis. Once teams could reliably score the VASI with the US team, they then proceeded to establish reliability with their local team before scoring the entire set of questionnaires they scored their entire sample and met with their local team to ensure 80% or greater inter rater reliability for each aspect of the VASI.

Data collection

This study took place at the start of the grade seven school 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/region. Countries in the Northern hemisphere collected data in August/September and the Southern hemisphere countries collected data in January). Each student was given a VASI questionnaire (Figure One) to complete in a 60-minute time period. In figure one below is a complete set of VASI questions, in the version distributed to the students there was adequate space for the students to answer.

INSERT FIGURE ONE ABOUT HERE

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. 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 SI. If a respondent provided a response consistent across the entire questionnaire that is wholly congruent with the target response for a given aspect of SI they were labeled as "informed". If, by contrast, a response was 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" was given. A response that is contradictory to accepted views of an aspect of SI, and provides no evidence of congruence with accepted views of the specific aspect of SI under examination, was scored as "naïve". See TABLE 1 for examples of coding for the VASI. At least 20% of the students were interviewed to ensure that the coding of the VASI was accurate. This insured face validity for the questionnaire. The interviews were recorded and transcribed. The inter rater reliability of the VASI was 80% or better for each site.

INSERT TABLE ONE ABOUT HERE

General Findings

Overall, this study found that grade seven students' understandings of scientific inquiry are poor. However, it was apparent that, for each country or region in the study, there were some students who held more moderate understandings. These variations differed from place to place depending on the curriculum. The following paragraphs highlight the findings from each country/region. Each site in the study wrote their own findings section. They wrote about the most interesting findings from their country/region. They also explained possible reasons for these particular results. See tables two and three for a complete set of data from each country/region for each aspect of SI measured in this study.

INSERT TABLE TWO ABOUT HERE

INSERT TABLE THREE ABOUT HERE

Every continent except, for obvious reasons, Antarctica are represented in the findings. What follows are country/region specific explanations (in alphabetical order) of findings and possible factors influencing SI understandings based on local standards and teaching practice.

Australia

Australian 7th grade students failed to express informed views of the majority of the aspects of scientific inquiry examined in this study. Most students held naïve or mixed views of six of the eight aspects, with half of the students expressing informed views in only two aspects. For the most informed aspects of SI, 51% of students exhibited informed views on *scientific procedures being guided by the question asked*, and 52 % for *conclusions being consistent with data collected*. Further, for the most naïve aspects of SI, 39% showed naïve views for *same procedures and the same results*, and 25% for *begins with a question*. Also, in four aspects, most students showed mixed answers: *Data does not equal evidence* (74%) where most students were unable to explicate that evidence is a product of data analysis procedures and interpretation. Seventy-one percent mixed answers for *procedures influence results*, 67% for *multiple methods*, 41% for *investigations must* *begin with a question*, and 58% for *Explanations are developed from data and what is already known* showing little understanding of the role of scientists' previous knowledge, and currently accepted scientific knowledge. In general, Australian 7th grade students enter high school with largely uninformed views of the nature of SI. On the whole, students showed adequate understandings of the need for alignment between research question and method, and claims being supported by data. Unfortunately, a lack of understanding of the role of data interpretation and previous knowledge the nature of evidence and experiments, and an inability to describe the multiple methods used in science, was also found. These findings are concerning as evidence suggests that inadequate views of scientific inquiry will hamper students' abilities to appreciate how the scientific enterprise operates, and may lead to disengagement in science in the post-compulsory years of schooling.

Brazil

The majority of Brazilian students' responses were classified as naïve for all aspects of SI. The most naïve aspects were: *All scientific inquiry begins with the question* (83.2%) where students expressed that the role of a scientific questions is not necessary for doing scientific research. For *same procedures may not yield same results* (82.8%) the answers showed that if scientists follow the same procedures they will think the same way, instead of associate the scientific reasoning conditioning to the procedures. For *procedures influence results* (81.1%) most of the answers hold the idea that there is only one type of procedure to answer a question while for s*cientific data are not the same as scientific evidence* (75.7%) and most students indicated that data and evidence are the same. For *procedures are guided by the question asked* (74.5%) students also showed naïve answers, therefore, it was clear that the students could not understand the question. For *multiples* *methods* (74.3%) a significant number of students responded positively to question 1c, they did not consider that the situation presented on the study of birds was a research method. For *conclusions must be consistent with data collected* (68%) among the responses the most commonly stated view was that the growth of the plant is subject to the amount of light without the students analyze the data presented. Finally, for *conclusions are developed from data and prior knowledge* (66.3%) although students based their explanations on anatomical and behavioral aspects of the animal, they failed to explain what knowledge allowed the conclusions. In overall, analyzing the responses of Brazilian students, it can be considered that they can conceptualize some SI aspects, but cannot identify them in real situations. This result reflects, the lack of national curricular proposals of SI to elementary school, the absence of experience of developing research in science class, or even because of the difficulty of understanding the questionnaire due to poor social, cultural and financial conditions of some of the students.

Chile

In general, most of 7^{th} grade Chilean students demonstrated naïve or mixed knowledge of the aspects of SI. The most informed aspect was *conclusions consistent with data collected* where only 26.1% of the students were able to read the chart and extract information. In the same aspect, 55.6% of the students showed a naïve answer. Students also showed over 50% of naïve answers in seven SI aspects: *Multiple methods* (75.4%) where the idea of "one scientific method" is not new in Chilean context. Even science textbooks and teachers continue transmitting that idea to students, *procedures are guided by the question asked (*67.6%) where students were not able to relate procedures and research question, s*ame procedures may not get the same results* (63.4%), *data does not* *equal evidence* (58.5%) showed that students had troubles defined them. *Explanations are developed from data and what is already known* (56.3%), and *begins with a question* (53.5%) where some students mentioned that questions are not necessary because scientific investigations can begin with observation of a phenomena or facing a problem. Moreover, mixed answers reached 50.7% for the aspect *procedures influence results.* In general, as a possible explanation for the lack of informed answers, we suggest that students seem to know the number of logical steps from a single scientific method with which they have been educated in science and they assume certain levels of intuitive coherence between them. Simultaneously, they rarely have opportunities to develop their own research questions and design investigations to answer those questions. As a result, they ignore how the results are related to the procedures utilized. Chilean students were unaware that there are several ways of doing science, possibly because both activities proposed by teachers, and by official science textbooks are based on the classic sequence of the scientific method.

China (Mainland)

Beijing. The results show that Chinese students from Beijing hold mostly mixed views the aspects of SI. The most informed aspects, *procedures are guided by the question asked* showed 57.2% of informed answers providing explicit correct explanations. Another informed aspect was *conclusions consistent with data collected* showing 36.7% of informed answers, but 46.4% of mixed answers for same aspect. One possible reason for these informed aspects is that these particular aspects of SI are mentioned to some extent in the national curriculum standards. Teachers in this region have students during lab work identifying variables related to research question, controlling variables, and developing conclusion based on the data collected. The most naïve aspect was *same procedures may* *not get the same result* (57.8%) where most students mentioned the "error" to justify differences among results. Additionally, more than half of the student hold a mixed view in five aspects: *Explanations are developed from data and what is already know* (81.9%), *procedures influence the results* (59%), *begin with a question* (56%), *data no equal evidence* (52.4%), and *multiple methods* (51.8%). Further, these two last aspects plus *same procedures may not get the same results* are not mentioned by standards even in implicit way to some extent. Neither argumentation nor social science issue (SSI), which were implied by some studies that might be correlated with some aspects of NOS. These also might be related with the eastern philosophies of education, such as Confucianism which have been extensively discussed in the literature it is a common belief that Chinese students are rote learners and choose passive approach to learning. Lau, Ho, and Lam (2015) pointed that the western students are relatively better in understating the process and the nature of science, while the East Asian students are relatively better in science contents than science process.

Shanghai. Students from Shanghai showed low level of understanding of SI in all the aspects considered in the VASI questionnaire. The most informed aspects showed no more than 30% of adequate answers. For example, for the aspect *conclusions consistent with data collected* only 29.6% students were able to provide and informed answers versus 60.7% naïve answers for the same aspect. Also, *begins with a question* showed 23.3% of informed views versus 56.3% of naïve answers. On the other hand, the most naïve aspects show low levels of understanding. 91.8% of students provided a naïve answer for *multiple methods* and similar value (90.3%) show a low level of understanding related with *data does not equal to evidence*. For *explanations are developed from data and what is already* *known*, 65.5% of the students provided a naïve answer. For *same procedures may not get the same results*, 57.8% expressed a naïve view for the aspect. Finally, p*rocedures can influence results* and *procedures guided by question asked presented 53.4%* of naïve answers each one. This last aspect also showed 22.3% of informed answer for the same aspects. Mixed answers represented less than 40% in only three aspects. Many possible factors can explain the results. First, SI is not sufficiently used in science classrooms. In Shanghai, 7th grade students learn science through lectures instead of SI activities because teachers consider that inquiry activities require more time and longer period of preparation. Second, it is not until 2001 that the reform of basic education started in China and SI began to be promoted. Further, science teachers have different understanding of SI and this contributes student's misunderstanding of science inquiry. Third, paper and pencil examinations are still a very important way to evaluate students' achievement in science learning. Thus, as long as they can get good scores, they are not required to understand knowledge of science inquiry.

Zhejiang Province. Students from Zhejiang showed informed views in four aspects of SI. They also hold mixed views for two SI aspects, and naïve views for another two SI aspects. In particular, the most informed aspects were *Procedures are guided by the question asked* (60.4%), *begin with a question* (59.4%), *explanations are developed from data and what is already known* (50%), and *conclusions consistent with data collected* (41.5%). One of the possible reason is that SI was described as both the objective and content in science curriculum standard. These four aspects were also stressed in the integrated science textbook. On the other hand, aspects that showed most naïve answers were: *Same procedures may not get the same results* (50%) where half of students provide inadequate answers and reasons. For example, one student said that every scientist has their own research method for the same question, and their style is different. The same phenomena in *Procedures influence results* (36.8%), however, in this case, the percentage of naïve answers is similar to informed answers (32.1%). Additionally, *multiple methods* (70.8%), and *data does not equal to evidence* (64.1) hold mostly mixed views. The possible reason was that these two aspects were not mentioned by science curriculum standard and integrated science textbook in explicit way to some extent, as well as in science teaching.

Egypt

At least half of the 7th grade students in Egypt showed "Naïve" answers for five of the eight SI aspects. The aspect of SI that had the highest percentage of 'Informed' responses was *conclusions consistent with data collected* with 34% versus 50% of naïve answers, most teaching methods that these students were exposed to and the way the exams are designed, would not indicate at all that students would be able to make a choice that contradicts with what they were taught in school and what they know. For s*ame procedures may not get the same result,* only 23% showed an 'Informed' answer versus 51% that provided a "Naïve" answer. Further, the students also showed most "Naïve" answers in the following aspects: *Procedures are guided by the question asked* (57%), *data does not equal evidence* (55%), and m*ultiple methods* (50%). In two aspects, students showed mostly 'Mixed' answers: *explanations are developed from data and what is already known* (73%) and b*egins with a Question* (55%). In general, it is possible to deduce that the students have some understanding of SI aspects, however they are confused and distorted, and this is shown in their answers that seemed to be fragmented and inconsistent. From the possible explanations of these results is that teaching science in the Egyptian context is based mainly on teacher centered approaches where there is little opportunity given to students for hands-on activity, group work or critical and creative thinking. Classes are usually overcrowded and laboratory experiences are minimal to teacher demonstrations. The curriculum emphasizes content over skills and it is test driven with an emphasis on grades and passing exams. There are some efforts done by individual teachers who try to shift to more student-centered approaches, yet with limited facilities, and a tight curriculum their efforts and impact seem to be limited.

England

Science teaching in elementary schools in England, that is key stages 1 and 2, is governed by the National Curriculum as shown at https://www.gov.uk/government/publications/national-curriculum-in-england-science-programmes-of-study/national-curriculum-in-england-science-programmes-of-study. By the last years of elementary school students are expected to be able to make their own decisions about setting up and conducting scientific inquiries but there is no specific mention of understanding the nature of scientific inquiry. Science itself is taught in a wide variety of ways with the majority of schools teaching some form of science weekly and around two-thirds combining this with other types of activity such as dedicated science weeks, science days and visits. According to the 2017 Wellcome Trust 'State of the Nation' report of UK primary science education, across all of these methods, science is taught on average in elementary school in England for 1.8 hours a week.

The sample comprised 103 Grade Seven students (aged 11-12 years) of mixed ability and mixed gender. The students came from four tutor groups, two each from two schools. One school was situated in a more affluent, central urban area and one in a less affluent, suburban area though both were cited in the same city in the South West of England. Thus the students came from families representing a wide range in socio-economic status though, given the high number of independent schools in the city, the wealthy are likely to be under-represented. English state schools arrange for tutor groups (set up for pastoral oversight of students) to have a representative mix of abilities so there was a good variety of ability within the sample covering the entire range available. The data from the two schools were pooled to make for a sample as representative of an English city as possible.

Most of 7th grade students from England demonstrated mixed and naive understanding about SI aspects during the VASI study. The percentage representing informed answers showed that only in three aspects, the informed views were over 20% of the sample: *Procedures are guided by the question asked* (36.9%) where the need for there to be a fair test in any scientific investigation is covered strongly in UK primary schools, c*onclusions consistent with data collected* (24.3%), and *data does not equal evidence* (22.3%). Additionally, in two aspects, more than half of the students provided naïve answers: *Same procedures may not get the same results* (58.3%) students missed the role of the scientist in interpreting the data and the resulting potential for different interpretations, and *multiple Methods* (56.3%) where many students referred to experiments rather than investigations. In the case of b*egins with a question* aspect, 39.8% expressed a naïve view. The percentage close to 50% of mixed answers in the two aspects e*xplanations are developed from data and what is already known* (48.5%) where many students were unable to take a more abstract perspective to think through how scientists develop initial explanations and *procedures influence results* (46.6%) indicated that just over half the students in each case were unable to provide a fully informed answer. In general, the results showed how students' views about scientific inquiry are heavily influenced by the structured approach to practical science found in many UK schools. Students will often be asked to repeat an experiment at least three times making sure they redo the method as accurately as possible to enhance the reliability of their results. They take pride in achieving consistency and 'a fair test' with the result that they are familiar with the concept that the methods used by a scientist in an investigation will affect its outcomes but not that different scientists may view these outcomes differently.

Finland

The Finnish students in this study hold mainly naïve and mixed conceptions in regards to the aspects of SI assessed by the VASI questionnaire. The aspects where a majority of the students did well were on; *Data does not equal evidence* (47%) and *conclusions consistent with data collected* (40.3%). In this last aspect, students showed similar number for naïve answers (40.9%). These aspects are addressed in both mathematics and science classes in Finland, additionally, they are heavily emphasized on the PISA exam. On the other hand, in two aspects, at least, half of the students expressed naïve views regarding *multiple Methods* (58.2%) where the item was challenging to Finnish students, and *procedures are guided by the question asked* (50.3%). Also, the aspect *begins with a Question* (38.3%) presented most naïve answers. In this case, students performed not well in this item. The most mixed answers were found in three aspects: *Same procedures may not get the same results* (54.4%), and *Procedures influence results* (44.3%) where those aspects are clearly in PISA math literacy, and e*xplanations are developed from data and what is already known* (42.5%) where the dinosaur question was performed rather well.

It looks some students were tired while answering the last questions. In general, it was found that the items that are reflected on the PISA exam are heavily emphasized in school and therefore students did well on them in the VASI. It should also be noted that students do not often engage in designing scientific inquiry and also did not do well in understanding how scientists go about constructing a question or a procedure. If these aspects were taught in Finnish schools the students would do better.

France

Based on the French students' answers to the VASI questionnaire, the children appeared to have a rather low understanding of the SI as measured by the VASI. The majority fall in the naïve and mixed categories. The most informed answers were provided for *conclusions and data collected* with 16% versus 48% of naïve answers for the same aspect. Further, two aspects showed over 70% of naïve answers, *multiple methods* (79%), and *explanations are developed from data and what is already known* (72%). Other aspects that showed naïve answers were *procedure influence the results* (53%), and *same procedures may not get the same results* (47%). Mixed answers were found in *procedures are guided by the question asked* (54%), *data does not equal evidence* (46%), and *begins with a question* (41%). The consistency of conclusions with data collected is one key feature of the "La Main à la Pâte" approach (Charpak, 1998), which is recommended to teach science at school since 2002. It is likely one aspect actually promoted by the teachers who have all followed in high school a year-long mandatory philosophy course, which traditionally emphasizes it. Most primary school teachers come from a non-scientific background. It can thus be conjectured that many of them are not at ease with explanations not only developed from data and with diversity of methods usually available to approach a given investigation aspects. Yet, the poor score of pupils on the latter refers more to their inability to justify their answer than to their belief in a single method. This VASI study thus draws a picture of an average French pupil still quite naïve, or at best mixed about the nature of scientific inquiry, when he/she enters middle school. This vision is in fair agreement with the result of national studies, such as CEDRE-2013 (DEPP, 2014) according to which only 9,9% of the pupils have mastered the principles of scientific investigation by the end of primary school.

Germany

German 7th grade students hold naïve views in four aspects of SI, mixed views for two aspects, and two informed views. The most informed views corresponded to *conclusions consistent with data collected* (52.1%) and *procedures are guided by the question asked* (47.9%), It seems that students show a high sensitivity for logical and conclusive arguing and reasoning. Also, the most naïve answers were expressed for *same procedures may not get the same results* (62.5%), *data does not equal evidence* (45.8%), *begins with a question* (41.7%), and *procedures influence results* (39.6%). It seems the students' views are rather influenced by the idea of "truth" in science. Then, science education not seldom conveys the view that there are wrong and one correct solution to a problem. Additionally, students showed mixed views in *multiple methods* (64.6%) and *explanations are developed from data and what is already known* (47.9%). The interpretation of the results is made considering the German National Science Education Standards (KMK, 2005a, 2005b, 2005c) which emphasize the importance of scientific competences such as doing inquiry. Students are expected to develop the ability to pose hypotheses, plan and perform investigations, control variables and analyze data. Although

7^{th} graders typically have had education in biology and physics, they express that they would not be able to define science or provide examples of a scientific investigation. One possible explanation might be that students have not been challenged to question their implicit use and were not able to answer the questions. Moreover, these aspects are unlikely to have been taught in school and it appears that the educational system lacks the explicit reflection of students' views and beliefs. The focus in the German educational system seems to be on conveying appropriate knowledge and has an emphasis on the mastering of skills and abilities related to autonomous knowledge acquisition and the correct implementation of working procedures.

Israel

In general, 7^{th} grade Israeli students showed naïve views in six of eight aspects of SI. Students hold informed views for two aspects: *Procedures guided by the question asked* (44.9%) and *conclusions consistent with data collected* (44.2%). For this last aspect, during the interview process, students were asked if they referred to "Data collected" or "Data analysis", however, they did not know how to differentiate between both. On the other hand, the most naïve aspects according to the analysis of student answers were *multiple methods* (47.8%), *same procedures may not get the same results* (46.4%), *explanations are developed from data and what is already known* (46%)*, procedures influence results* (45.7%), *begin with a question* (44.2%). For this last aspect, some students expressed that scientists may do various experiments in their laboratories with the materials and instruments which they have, and see what they get. They do not necessarily invent a question. *Data does not equal evidence* (39.5%) also showed naïve views. Additionally, during the interviews, students tried to explain the meaning of data/evidence, but they were quite confused about it. As a part of the conclusions, students in general, learned these concepts, but they do not really assimilate them correctly. Further, the inquiry approach to teaching and learning is not done in a thorough way. The inquiry concepts were somehow "transmitted" in a declarative way, and the inquiry procedures were somehow neglected. Finally, the science curriculum for junior high schools in Israel (6^{th}-8^{th} grades) includes mainly biology topics, and emphasizes the nature of science as well as inquiry procedures and skills. We therefore believe that quite a lot of students were correct about some categories, but when interviewing a few students who answered the questionnaire, we found out that they just repeated what they were told in class, rather than really understanding the issue.

New Zealand

New Zealand 7^{th} grade students tend to hold naïve views in almost every aspect of SI. Students provided more informed answers in relation to *begin with a question* (26.4%) and *procedures are guided by the question* (25.3%). However, the same SI aspects showed 37.9% and 48.3% of naïve answers respectively. This result suggests that while students may have some understanding of the purposeful nature of scientific investigations, this understanding is not always modelled in science classrooms. On the contrary, two aspects showed over 70% of naïve views. *Explanations are developed from data and what is already known* (78.2%) and *same procedures may not get the same results* (71.3%), where most students suggested that different conclusions would result from the same procedures because of experimental error and/or experimental variation. Other naïve aspects were *procedures influence results* (64.4%), *multiple methods* (63.2%), and *conclusions consistent with data collected* (42.5%). Further, the aspect of *data does not equal evidence* indicates mostly mixed results (41.4%), with a large proportion of the responses referring to everyday interpretations of the words, such as 'data' referring to Internet download capacity, and 'evidence' being associated with a legal context. In conclusion, although the New Zealand Curriculum in science sets expectations related to understanding key aspects of SI (e.g., appreciate that scientists ask questions about our world that lead to investigations, and that scientists provide evidence to support their ideas), science often has low status in the curriculum of many primary schools. The causes are multiple but contributing factors include the lack of systemic support for teaching science by way of in-service professional development; primary teachers' resulting low sense of self-efficacy in science teaching; and the introduction of national standards in numeracy and literacy with a consequent shift in focus on these areas, sometimes at the expense of other areas, including science. The New Zealand government has responded to concerns about students' engagement and achievement in science, as measured by national and international testing, with a number of initiatives including a nation-wide 'Plan for Science in Society'.

Nigeria

Nigerian students from 7th grade mostly hold naïve views for six aspects of SI. They also showed informed understanding in two aspects. For the most informed aspects, 54.9% showed informed views for *procedure influence results* and 36.3% for *data does not equal evidence*. On the other hand, students showed most naïve views on *same procedures may get the same results* (77.5%), *multiple methods* (68.6%) *procedures are guided by the question asked* (61.8%), *explanations are developed from data and what is already known* (60.8%), *begins with a question* (57.8%), and *conclusions consistent with data collected* (42.2%). In conclusion, it is desirable that students be informed on SI and one possible explanation for the results could be that Nigerian students had this comparative better performance because the instructional system to which they are accustomed is one that foregrounds procedures. In their learning experiences, they have some familiarity with following laid down steps and structures of organization of ideas. On the other hand, considering the aspect *same procedures may get the same results* (77.5%), it is possible to infer coherence between this and their largely formal view of the influence of procedures on results. Students may see a paradox in how one could assert that procedures influence results, and then simultaneously hold the view that same results may not get the same results. So, they may have been operationalizing the logic that some procedures, then same results.

South Africa

Seventh grade students in South Africa showed mostly naïve and informed views of SI. Students were considered informed for *begins with a question* (48%), *conclusions consistent with data collected* (48%), and *procedure influence results* (39%). Further, more complex aspects involving human imagination and creativity, such as *same procedures may not get the same results* (57%), and *procedures are guided by the question asked* (53%) hold most naïve views. Also, *data does not equal evidence* (51%) showed mostly naïve views. The poor understanding of this aspect may be understood in terms of inadequate vocabulary due to second language usage. Additionally, *explanations are developed from data and what is already known* (67%) and *multiple methods* (42%) showed mostly mixed answers. In conclusion, over the past 20 years, education in South Africa has been subject to three curriculum changes, seeking a balance between learning content and skills development. Throughout the curriculum changes, conducting investigations remained a focus, although the reality of poorly trained teachers often limits opportunities for learners to conduct investigations. Nevertheless, throughout the changes, the curriculum and textbooks have placed a strong emphasis on asking questions, collecting data and making conclusions. It is therefore plausible that teachers emphasize these ideas even though learners themselves seldom have opportunities to engage practically in inquiry. Therefore, learners may develop some unexpected understanding of some inquiry aspects emphasized by the curriculum, as argued in an earlier South African study using Grade 11 learners (Gaigher, Lederman, & Lederman, 2014). It is thus not surprising that learners in the current study are best informed on aspects focused on questions, data and conclusions, while aspects involving the human mind in relating these ideas are poorly understood.

Spain

The Spanish students hold a naïve understanding for all the aspect of SI. In all of them, at least half of the sample showed naïve views. On the other hand, students showed the most informed answers in two aspects, *conclusions consistent with data collected* (37.7%) and *procedures are guided by the question asked* (32.1%). However, these values are not very significant if they are compared with the naïve answers in the same aspect (47.8% and 54.1% respectably). Additionally, the most naïve views are found in *multiple methods* (83.6%) where It seems that students have a reductionist view about the scientific method, *data does not equal evidence* (78%), *explanations are developed from data and what is already known* (73.6%) students expressed difficulties interpreting the information in charts as well as having a naive conception of it, *same procedures may not get the same results* (68.6%), *begins with a question* (65.4%) where some students mentioned that the questions are not important because scientific research can begin with the observation of a phenomenon or problem, with experimentation or testing, and *procedures influence results*

(62.9%). In general, one of the reasons for the result is the lack of students' understanding about science and SI. Students seem able to use scientific reasoning, but they are unable to understand the phenomena that affect them in their day to day lives. Another reason that may explain these results is related to teaching methods and content. These include the lack of SI as relevant science curricular content, lack of adequate understanding of the aims and objectives to facilitate their inclusion in science lectures, resistance against reforms and educational innovations, lack of an explicit and reflexive teaching of SI, lack of effective teaching approaches to teaching of SI, and performing SI reflective activities (exploration, analysis, debate, discussion, argument, etc.).

Sweden

Most of the 7th grade students from Sweden hold naïve understanding for the aspects of SI assessed by the VASI questionnaire. The most informed are observed in *begins with a question* (29.4%) and *conclusions consistent with data collected* (28.6%) aspects. However, similar values for naïve answers are shown in the same aspects (30.2% and 30.2% respectively). The most naïve views are found in *data does not equal evidence* (55.6%), *procedures are guided by the question asked* (42.9%), *explanations are developed from data and what is already known* (36.5%), and *procedure influence results* (31%).Further, *same procedures may not get the same results* (35.7%) and *multiple methods* (32.5%) showed mostly mixed answers. In general, the term "science" and "scientific" does not seem to be used that much in science education at this level in Sweden, but the reason may be that the school subject is often called "nature orientation", or "nature orientation subjects". In other schools, science education is broken down into biology, chemistry and physics and this is what students and teachers would refer to then. So, unless SI is addressed as an explicit topic, which seems rare, words like “science” and “scientific” may not be used in any systematic way in these schools. Students do not seem to have had any systematic teaching regarding the nature of SI and related concept such as experiment. In spite of this many students still seem to have a fair understanding of the basic principles of an experiment as involving some active manipulation to test how one thing affects another. Evidence and data were terms virtually all students had difficulties with in the Swedish context and the interviews indicated that these were not used or addressed in their science class. Finally, students tend to relate research and inquiry to their own school tasks such as laboratory work and finding information on the Internet rather than scientific inquiry per se.

Taiwan

The results show that Taiwanese 7th grade students hold, mostly, mixed views about the aspects of SI. Overall at least one third of the students showed mixed views in six aspects. The most informed aspects, c*onclusions consistent with data collected* and *same procedures may not get the same results* show 50% of informed answers each one. In this case, students seemed to be able to answer these questions intuitively since the questions are structured with certain options. On the other hand, the aspect with the most naïve views corresponds to *explanations are developed from data and what is already known* (41.9%) followed by *multiple methods* (37.1%). The naïve view of the former may be owing to students' unfamiliarity with the dinosaur scenario that has not been included in elementary science textbooks. Meanwhile, the naïve view that a single set of steps must be followed in science apparently comes from the figures presented in the first unit of biology textbooks. Additionally, *procedures influence results* (52.1%), *procedures are guided by the question asked* (50.3%), *data does not equal evidence* (44.9%), and *begin with a question* (38.9%)

where many students considered the context of questions not always within the scope of science but from everyday life, showed mixed understandings. It is noted that students' responses largely reflect the image presented in school science as shown in the translation of specific terms such as *experiment*, *the scientific method, data and evidence* in the textbooks, and *natural science* versus *Nature & science* for the title of the course. In Taiwan, science textbooks are shaped by national science curriculum guidelines, which is now under reform and the teaching of SI will be much emphasized. The assessment results of this study can serve as a baseline for comparisons when the new curriculum guidelines are implemented.

Turkey

Most of the 7th grade Turkish students hold naïve views for each aspect of SI. Students had naïve ideas especially for the intrinsic properties of SI. The best understood aspects were *conclusions consistent with data collected* (26.5%) and *explanations are developed from data and what is already known* (13.8%). However, these results contrast with the percentage of naïve answers for the same aspects (54.5% and 48.5% respectively) and this may be due to rote learning activities which are not uncommon in typical Turkish science classrooms. In contrast, *procedures are guided by the question asked* was the poorest understood aspect of inquiry with most naïve answers (72.8%). Similarly, *begins with a question* (70.2%), *multiple methods* (67.2%), *same procedures may get the same results* (63.8%), *data does not equal evidence* (60.5%), and *procedures influence the results* (59.7%) evidenced naïve views. In general, the results indicate that the science curriculum and the science education as a whole in Turkey does a poor job of preparing students for understanding SI. SI is an integral part of scientific literacy and despite being mentioned as a goal in the curriculum, the students showed mostly naïve views of SI. Although all aspects were not fully understood properly by the participants, it is interesting to see that they presented relatively more informed understandings in two aspects of SI. Both of these aspects have to do with data interpretation and inference. Another explanation for the results focus on "teaching to the test". Since there is a high stakes exam at the end of middle school, teachers tend to ignore emphasizing SI process and give drill instruction about how to read graphics and interpret a given set of data. So, data interpretation and drawing conclusions are explicitly taught while the process of scientific inquiry is ignored.

United States

Overall, the results demonstrate a lack of sufficient understanding of all targeted SI aspects, with 50% or more of the participants falling within the naïve range. Participants were most challenged with *multiple methods* (74.4% naive), *Explanations are developed from data and what is already known* (70.7%) and *data does not equal evidence* (72% naive).

Within the informed range, a few participants demonstrated some understanding of *conclusions consistent with data collected* (34.1% informed). Those who responded appropriately for this aspect were clear to connect the claim with available evidence. However, others either did not provide any evidence, basing their claim on their preconceived assumptions; or connected their claim only to those data that supported their claim, ignoring data that do not align. Regarding *the influence of procedures on results*, many participants expressed that the only way the same procedures would lead to different results was through an error. Similarly, when asked about the position of the dinosaur bones and reasons for one being more acceptable than the other, 34% of the participants gave absolutist type responses such as "figure 2 is wrong" or "figure 1 is how they look."

Overall the U.S. students were naïve in their understanding of SI. This is probably because of the lack of explicit instruction given to SI in the elementary level classroom. Understandings about SI are not clearly emphasized in the NGSS. They are included as connections to NOS with the dimensions of "Science Practices and Crosscutting Concepts." In short, it is assumed that students will learn about scientific inquiry simply by doing inquiry.

Conclusions and Implications

Overwhelmingly, the results from this study show that students around the world have an overall naïve view of scientific inquiry, although there were instances in which students in a country did better than "naïve" on a particular aspect of SI. This is consistent with the studies that have been done with secondary students, pre service and in service teachers. The findings are not surprising since students are rarely taught understandings of inquiry in an explicit, reflective manner. Further, it is evident from the specific descriptions of how science is taught in the various countries/regions that knowledge about inquiry is not taught in an explicit/reflective manner, it is not included in the curriculum, and in some cases students rarely, if ever, have the opportunity to actually conduct scientific investigations. It is clear that no matter where students live worldwide that understandings of inquiry are not cultivated. It is important to note that no statistical comparisons were made among the countries as the purpose here was just to get a baseline of beginning middle school students' understandings. Statistical comparisons across countries would be inappropriate because of the vast differences that exist with respect to curriculum, teaching approach, and cultures across the 18 countries/regions included in this investigation. As humans, we are all too often tempted to compare our own country's performance against other countries, but this is really inappropriate and unfair. However, it is important to note that despite all of the possible differences across countries/regions with respect to curriculum, teaching approach, and cultures the results are quite consistent with respect to students' lack understanding about inquiry.

Completion of elementary school is about half way through a student's schooling and the data collected in this study indicate that most students hold a naïve view of most of the aspects of SI in seventh grade. These findings are not surprising as a cross sectional study conducted in the US found that students' understandings of SI do not increase between grades one to five and in the case of some aspects their understandings decrease through elementary school (Bartels & Lederman, 2017). Some may argue that the students in this investigation will have plenty of time to improve their understandings and are not that poor considering that students have just completed elementary school. However, previous studies have found that very young children (grade one and above) are able to adequately understand several aspects of scientific inquiry; science begins with a question, there is no single scientific method and conclusions are based on data gathered and what is already known (Lederman, J., 2012). Another study looked at grade one students' understandings of SI who came from very different cultural backgrounds, this study found that after explicit and reflective science instruction grade one students could understand aspects of SI regardless of their initial SI understandings (Lederman, Bartels, Liu, &

Jimenez, 2013). Students should, at the very least, have informed views of at least some of the aforementioned aspects by grade seven.

An important caveat, other than avoiding the temptation of comparing countries/regions, is that the primary goal of this investigation is to establish an initial baseline of what students understand about scientific inquiry. Understandings of scientific inquiry is a highly prized goal of science education throughout the world and it is a significant component of scientific literacy (Roberts, 2007). It is quite possible that not all countries/regions will care equally about each of the eight aspects of SI investigated here. Consequently, they may not be concerned that their students, for example, do not understand the difference between data and evidence. However, this investigation provides data on some aspects that are assuredly of concern and importance to certain countries/regions and the results can lead to changes in curricula, science teaching and policy in science education.

Implications for Future Research

Currently, the 18 countries/regions involved in this investigation, along with an additional seven countries/regions are looking at graduating high school students' understandings of SI. This will provide information about how, and if, students' understandings of SI become more sophisticated as they proceed through middle and high school. The final piece of students' trajectories of SI understandings can be completed by assessing elementary students' understandings of SI as they enter school. The results from all three of these studies combined will elucidate a full progression of students' SI understandings from beginning elementary school to the completion of high school around the world.

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