Understandings About Scientific Inquiry in a South African School Prioritizing STEM

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Abstract

This paper reports on a case study of South African Grade 12 learners' views about scientific inquiry. The study focuses on a non-fee-paying government school that receives curricular support and resources to specifically develop Science, Technology, Engineering and Mathematics (STEM) teaching in a low socioeconomic setting. Data were collected using the Views About Scientific Inquiry (VASI) questionnaire. The learners demonstrated high levels of understanding of some inquiry aspects, while other aspects are poorly understood. The best understood aspects relate to questions, data and conclusions, whilst the aspects related to multiple methods, previous knowledge and differences in interpretations are poorly understood. Results were compared to those of Grade 12 learners at other South African schools who also completed the VASI Questionnaire. The findings suggest that the case study school's emphasis on STEM and high performance may support understandings of scientific inquiry in general, but at the same time encourage some naïve views such as believing that scientific investigations are rigid processes, independent of human creativity.

Keywords: Science Education; Inquiry; Views about scientific inquiry; South Africa

Introduction

Science education worldwide places much emphasis on Scientific Inquiry (SI) in school curricula (Abd-El-Khalick et al., 2004). Scientific inquiry refers to knowledge about the combination of "general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge" (Lederman et al., 2014). It is widely argued that learners should be involved in inquiry activities in order to learn the content of science as well as the skills of scientific investigating in order to acquire scientific literacy (for example, Gyllenpalm et al., 2021). Besides undertaking inquiry, learners should also develop an understanding about the Nature of Scientific Inquiry (NOSI) (Bybee, 2000; National Research Council [NRC], 2012). South Africa's alignment with such views is evidenced in the current Curriculum and Assessment Policy Statement (CAPS) for Physical Science (DBE, 2011) where the purpose is stated as follows:

> The purpose of Physical Science is to equip learners with investigating skills … designing an investigation, drawing and evaluating conclusions, formulating models, hypothesising, identifying and controlling variables, inferring, observing and comparing, interpreting, predicting … Physical Science promotes knowledge and skills in scientific inquiry and problem solving [and] an understanding of the nature of science and its relationships to technology, society and the environment (DBE, 2011, p. 8).

These features of the Nature of Science (NOS) underpin the understanding of the Nature of Scientific Inquiry (NOSI). In the 21st century, citizens need such knowledge to evaluate scientific claims to inform their scientifically based decisions in a world increasingly relying on the products of science and technology (Wiblom et al., 2020; Zeidler et al., 2005). However, undertaking SI is not a sufficient condition for developing sophisticated understandings about NOSI; instead explicit instruction is required (Wong & Hodson, 2009). Research indicates that neither teachers nor students typically hold informed views about NOSI (Lederman et al., 2014).

The call for developing learners' knowledge about the inquiry process has led to the development of an instrument, the Views About Scientific Inquiry (VASI) questionnaire (Lederman et al., 2014). This instrument has been used in two large scale international collaborative studies for Grade 7 and Grade 12 learners (Lederman et al., 2019; 2021). South Africa participated in both these studies. The purpose of these two studies was to obtain a worldwide, overall baseline of learners' understandings of NOSI. Comparisons between countries were not made in these studies due to variations in curricula and cultures across countries. Findings of the Grade 12 study indicated that by the end of the school career, the proportion of students judged to have informed understandings of NOSI averaged below 45 % worldwide. Comparing the Grade 12 and Grade 7 results shows a trend of improved understanding of NOSI amongst Grade 12 learners. According to Lederman et al. (2021), this trend can be attributed to expanded science content knowledge as well as cognitive development during the secondary school years. The same trend was found in a longitudinal study in Sweden (Gyllenpalm et al., 2021). One may ask whether even better understanding of NOSI is possible amongst Grade 12 learners in schools that are specifically supported in STEM teaching.

In South Africa, science education experiences multiple challenges, such as a shortage of qualified teachers, poor resources and inadequate infrastructure (Amnesty International, 2020; Ogunnyi & Rollnick, 2015). Participation in international science studies such as the Trends in International Mathematics and Science Study (TIMSS) repeatedly produced dismal results where South Africa's performance has been typically ranked amongst the lowest (Mullis et al., 2020). Furthermore, the national Grade 12 final school results annually produce poor results for physical science, with less than 40% of learners scoring above 40% (DBE, 2016). This situation of South African learners' general poor performance in science is believed to contribute to the ongoing shortage in the scientific workforce in the country. There have been isolated initiatives to support selected schools in disadvantaged communities to enhance performance in science and mathematics. The nature of the support ranged from additional resources such as laboratories and equipment to curriculum support for the academic programme.

One such initiative was the Dinaledi (a SeSotho word meaning 'stars') schools project, initiated by the Department of Education as part of the National Strategy for Science, Mathematics and Technology (DOE, 2011). This project aimed to improve performance and to increase participation in mathematics, life sciences and physical sciences in disadvantaged schools (DBE, 2012). While such efforts resulted in improved academic performance at the end of high school (DBE, 2012; Lemmon, 2017), it is not known whether there is a similarly improved understanding of NOSI in such science-supported schools. For this reason, the current study explores Grade 12 learners' understanding of NOSI in a particular school that received support to develop STEM teaching and learning. The following research question is addressed:

How can the understandings of the nature of scientific inquiry of Grade 12 learners in a South African school supported in STEM education be characterized?

Conceptual frame

The National Science Education Standards (NRC, 2000) distinguishes the ability to do inquiry from an understanding about the nature of scientific inquiry. Though scientists may not agree completely on the nature of SI, Lederman et al. (2014, p. 68) compiled a set of eight essential aspects describing the NOSI aligned to the vision of the Next Generation Science Standards (NGSS Lead States, 2013).

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

The VASI questionnaire is based on these aspects of SI. The authors of the VASI instrument (Lederman et al., 2014) claim that there is general agreement that these aspects are relevant to schoolchildren and within their grasp. Therefore, the set of eight SI aspects is an appropriate conceptual frame for the current study.

Method

Context of the case study school

A case study design was used for this research project. All the participants were Grade 12 learners at a public high school which is a Science, Technology, Engineering and Mathematics (STEM) supported school in the Western Cape region, South Africa. The school was established in 1999 and is located in a low-income area with parents working as labourers or office workers while some are unemployed. It is a non-fee-paying high school based in a township offering Grades 8 – 12. The school which was included in the Dinaledi Project (Western Cape Education Department, 2012), referred to earlier in the introduction, and supported and funded by the National Department of Education, the Western Cape Education Department and a private trust (Lemmon, 2017). The nature of the support to the school takes on many different forms. The school is well resourced and has equipped laboratories, a well-stocked library and information and communication technologies. The laboratories where learners are taught have digital interactive smart boards with access to software such as Physics Education Technology (PhET) interactive simulations that also include other science disciplines and GeoGebra (interactive geometry, algebra, statistics and calculus applications). All teachers are qualified to teach their STEM subject specialisations and continued professional development is offered to the teachers as well as teachers from other public schools in the region through the Cape Teaching and Learning Institute (Western Cape

Education Department, n.d.). This particular school was chosen for being easily accessible and willing to participate. The school offers the following subjects all being compulsory parts of the curriculum: requisite languages, mathematics, physical science, life science and computer studies. To be admitted to the school, learners who have shown their potential and interest in STEM are required to pass a Mathematics and Natural Science admission test with at least 60%. The language of instruction at the school is English while isiXhosa is the mother tongue of almost all of the learners. An evaluation study of the academic performance of the school's results in the Grade 12 National Senior Certificate exam reported that results were similar to that of middle-class schools in the same region (Western Cape Government, 2015).

While the formal curriculum, CAPS, implemented at the school aims to promote knowledge and skills in scientific inquiry and an understanding of the nature of science and its relationships to technology, society and the environment (DBE, 2011), learners also take part in extracurricular activities where they are exposed to scientific inquiry. The science teachers offer after school workshops where learners are mentored and coached to participate in the annual Eskom Expo for Young Scientists (2020) competition. The mission of the Eskom Expo for Young Scientists (2020) is stated in the Expo Project Guide Book as "develop young scientists who are able to identify a problem, analyse information, find solutions and communicate effectively" (p. 3). The Expo Project Guide Book further lists one of the project types as "Scientific Investigation/Experimental: these are projects that follow a method that answers a research question and tests a hypothesis, usually through observations and experimentation" (Eskom Expo for Young Scientists, 2020, p. 4).

The sample and data collection

All the Grade 12 learners in this school were invited to participate in the study. A total of 110 learners agreed to participate. They were given the VASI questionnaire (Lederman et al., 2019) to complete in the presence of two of the researchers and the school's principal. Learners had 60 minutes to complete the questionnaire and a few learners (14) who required more time were granted extra time. Some examples of typical items for the eight different SI aspects have been included in the Results section of this article. The questionnaire had been validated by Lederman et al. (2014).

As required for the international project, 20% (22) of learners were interviewed one month later by reviewing their own VASI responses again to explain what they meant with their original responses. This process ensured that scoring of the VASI questionnaire was valid. Interviews lasted between 20 to 25 minutes and were audio recorded.

Data analysis

Learners' answers to the questionnaire and in the interviews were rated as informed, mixed or naïve, using the guidelines developed by Lederman et al. (2014), and also used in the international Grade 12 study. These scoring criteria are available in table format in Gaigher et al. (2014), and a typical example is included in the Results section. Three researchers participated in the scoring process independently, after which scores were discussed and adjustments negotiated where different scores had been assigned. An inter-rater agreement of 80% was attained.

The research was conducted according to ethical research procedures prescribed by the School of Education Ethics Committee at the University of Cape Town. Informed consent was obtained from parents or legal guardians of learners participating in research activities.

Results

The first question on the VASI questionnaire is conveniently selected to illustrate some of the responses and scoring. Question 1a and 1b test the SI aspect *"Scientific investigations all begin with a question but do not necessarily test a hypothesis"*. Question 1b and 1c test SI aspect 2 *"There is no single set and sequence of steps followed in all scientific investigations (i.e., there is no single scientific method)"*. Table 1 presents question 1 as well as examples of written responses and the scoring thereof.

Table 1. Examples of learners' responses to question 1 of the VASI to illustrate answers that were scored as naïve, mixed and informed

Question 1

A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds who eat similar types of food, tended to have similar shaped beaks. For example, birds that eat hard-shelled nuts have short, strong beaks, and birds who eat insects have long, slim beaks. He wondered if the shape of a bird's beak was related to the type of food the bird eats and he began to collect data to answer that question. He concluded that there is a relationship between beak shape and the type of food birds eat.

a. Do you consider this person's investigation to be scientific? Please explain why or why not.
b. Do you consider this person's investigation to be an experiment? Please explain why or why not.
c. Do you think that scientific investigations can follow more than one method?

If no, please explain why there is only one way to conduct a scientific investigation.

If yes, please describe two investigations that follow different methods, and explain how the methods differ and how they can still be considered scientific.

Examples of scoring of learners' answers

	Naïve	**Mixed**	**Informed**
a	No it is not scientific because no scientific methods were used to gather the data. He just collected the data by looking at different types of birds and the food they eat. (Questionnaire 12)	Yes it has an investigative question and a conclusion and he collected data to answer his investigative question. And he was able to collect data that would help his wonder the relationship between the type of food and the beak of the bird. (Questionnaire 4)	Yes. It has a solution or conclusion to a question he had on scientific things about problem solving. (Questionnaire 18)
b	Yes it is an experiment because in an experiment you look at to see whether there is a relationship between certain variable which in this case would be the beak shape and the type of food. (Questionnaire 12)	No because he did not experiment on anything nor are we told what variables he had. The only thing that he did was to collect data so this would be rather a study where data was collected to answer a question the person had. (Questionnaire 4)	No. He did not try to manipulate any things or variables. He only collected data and concluded from these results. (Questionnaire 18)

c	No to obtain the same results, an investigation has to be done in a certain way. (Questionnaire 12)	No because the one method ensure that your investigation is recognized in the scientific world. It also ensures the efficiency of an investigation and makes sure that the investigation is done thoroughly. (Questionnaire 4)	Yes. Researching through data collection of maybe people who have TB and evaluating results, or through making different samples of manipulating variable to check for similarities or differences. 1. Data collection through questions interviews etc. or 2. Experiments and creating your own data. (Questionnaire 18)

We also provide an example of an answer to question 2, which also tests understanding of SI aspect 1 *"Scientific investigations all begin with a question but do not necessarily test a hypothesis.* The question was as follows:

> Two students are asked if scientific investigations must always begin with a scientific question. One of the students says "yes" while the other says "no". Whom do you agree with and why?

One of the responses coded as informed was:

> I agree with the student who says 'yes' because there should always be a question to drive and guide any investigation. Our teacher always said that a science problem must be changed into a scientific question" (Informed, Questionnaire, 74).

In the interview the same learner was asked whether she still agreed with her answer, which she did, and if she could explain what she meant by "scientific question" and how she distinguished between a "scientific question" and a regular question. The learner decided to use the context of the scenario in the first question on the VASI questionnaire to offer an example of what she understood a 'scientific question' to be. In fact, she provided two questions and also judged one of the questions to be "better" for this particular context than the other one:

> I think asking 'Is there any relationship between birds' beak shapes and the kinds of food they eat' is better than asking 'what kinds of food do different birds eat? (Informed, Interview, 74).

Probing further why she thought these are scientific questions she explained that *"you have to go out and check out a variety of birds in nature to collect info on the foods they eat"*. From this response it appears that she knows that a question is required to direct the investigation and that this particular investigation would not test a hypothesis. We considered this response as evidence that the learner satisfied the criteria for having an informed view of aspect 1. What is noteworthy is that she remembered that her "teacher always said" which alluded to explicit teaching of this aspect of scientific inquiry that seems to have translated into this learner's informed understanding.

The results of the analysis of the participants' answers are summarized in Table 2. For four of the aspects, more than 45% of respondents were judged to hold informed views, exceeding the international averages (Lederman et al., 2021). The highest number of informed views was for the aspect *all investigations start with a question and do not necessarily test a hypothesis* (68.2%), followed by *conclusions must be consistent with data* (58.2%), *data and evidence are not the same* (50.9%) and *procedures are guided by the question* (46.4%). Amongst the eight aspects, these four tend to be straight forward, focusing on aspects of inquiry that do not foreground the involvement of human creativity.

Table 2: Distribution of VASI scores for each scientific inquiry aspect (N=110).

Inquiry Aspect	**Naïve %**	**Mixed %**	**Informed %**
Starts with a question and do not necessarily test a hypothesis	20.9	10.0	68.2
Multiple methods	40.0	27.3	17.3
Same procedures may not yield same results	38.2	25.5	35.5
Procedures influence results	25.5	30.9	39.1
Conclusions must be consistent with data	12.7	25.5	58.2
Procedures are guided by the question	26.4	16.4	46.4
Data and evidence are not the same	19.1	25.5	50.9
Conclusions are developed from data and prior knowledge	20.0	56.4	20.9

The next best understood aspect was *conclusions must be consistent with data* (58.2%) and was tested by item 6 in the questionnaire where a table showed a relationship between plant growth in cm per week and the daily number of minutes of light exposure. Learners were then required to agree with one of three possible conclusions based on these data, and to motivate their answer. The typical naïve answer was to choose alternative "a", i.e., that plants grow higher if they get sunlight, motivating their answers with arguments based on their previous knowledge of plant growth and photosynthesis and not based on the tabulated data. On the other hand, a typical informed view was exemplified by a student selecting option "b" (Plants grow taller with less sunlight) and wrote:

> When looking at the table, I first thought that the results were incorrectly captured because the logical thing that happens is that plants normally grow with exposure to sunlight, unless the soil is not fertile or it is a drought. But we have to stick to the evidence which tell me that growth rate diminishes in proportion (not linear though) to the increase of the number of minutes of light per day and thus I argue for option "b". (Informed, Questionnaire, 66).

The aspect, *data and scientific evidence are not the same,* was the third best understood aspect and 50.9% of the learners had informed views of which one example was articulated as follows:

> Data you collect from your experiment is transformed into evidence when data become results that answer the question of your science problem. (Informed, Questionnaire, 63).

In the follow-up interview the learner was probed to clarify what she meant by "data is transformed into evidence". She explained that "transformed" for her meant "working with data". She continued saying "I write it down in a table…like the one in this test where the columns show the number of minutes of sunlight and the length of the plant's growth [she pointed to the table in question 6 on the VASI questionnaire] … umm…then I analyse it and you have to think about it and then you write a conclusion". In the interview the learner decided to use the term "conclusion" and the term "results" was not used again. The term "results" can be ambiguous as it could mean "data collected" or "conclusion drawn" but the interview excerpt clarified for the scorers that the learner meant "conclusion". Combining the learner's responses from the questionnaire and the interview, this view resonates well with the exemplary informed view response in Lederman et al. (2014, p. 78) which states: "Data is stuff you observe from an experiment, evidence is organized data making them support the conclusion".

The least understood aspects are those NOSI aspects dealing with human creativity, such as the planning and designing of investigations and of interpreting results, showing close to 40% naïve views, such as *multiple methods* (40.0%) and *same procedures may not yield the same results* (38.2%).

It is noteworthy that several of these naïve answers for *multiple methods* displayed familiarity with scientific terminology, as in the following answer to question 1c:

> There is only one way to conduct an investigation. You first identify the dependant and independent variable, the controlled variable and then form an investigative question that help you with a solution. (Naïve, Questionnaire, 29).

The familiarity with scientific terminology is ascribed to the STEM focus of the school. Another example of a naïve response that clearly illustrates the myth of a single scientific method is that "all experiments follow the scientific method to come to a conclusion" (Naïve, Questionnaire, 44). In an interview with a learner who had a naïve view of this aspect, he referred to a "template":

> I really like the template in our project book. I also used it last year for my Expo thing. It helps you to not miss any steps in the prac work report. (Naïve, Interview, 28).

His teacher confirmed that the Project Guide Book (Eskom Expo, 2020, p. 35) was indeed used. An extract is presented in Table 3.

Table 3. Extract from the Eskom Expo Project Guide Book

Scientific Investigations/Experiments
<u>Introduction:</u> **Literature review:** Mention your background reading/literature review here. What research has already been done? etc. **Problem Statement:** What problem/issue will you be addressing? **Research question(s):** Questions asked must be researchable and answerable within the research timeframe and must be relevant to the research project, (Must not be a YES or NO answer, it helps focus your research and guides your methods etc.) **Aim:** What is the aim/objective of this research project? **Hypothesis:** Is a statement or claim that can be tested scientifically. Your research will test the hypothesis to accept/reject it or to see whether it is correct/incorrect, etc. **Variables:** List the independent, dependant and he controlled/fixed variables.

Note that under the heading “Variables” learners had to list the independent, dependant and the controlled/fixed variables for the scientific investigation.

Similarly, a naïve score for *same procedures may not yield the same results* (38.2%) was allocated to a response that stated:

> The same procedures and same order of doing each of the steps should lead to the same deductions or conclusions, otherwise consistency in science gets lost”. (Naïve, Questionnaire, 40).

This response indicates a view of science as an external reality independent of human creativity.

Mixed views were prominent for only one of the aspects, *conclusions are developed from data and prior knowledge* (56.4%). This aspect involves a merging of two types of information; firstly, information obtained during a particular investigation in the ‘real’ world and secondly, information accumulated over time as the collective body of knowledge of science. The mixed views of the majority suggest that most learners do not appreciate the combined power of new information and the existing science knowledge. One succinctly informed written response example was:

> A scientist has to compare his notes and bone fragments of the dinosaur skeletons with books and bones in Izeko [referring to Iziko, a museum in Cape Town]. (Informed, Questionnaire, 92).

The remaining two inquiry aspects show evenly distributed levels of understanding. These are *procedures influence results* and *same procedures may not yield same results*. Both these aspects confront the view that there is only one possible outcome for an investigation. For both these aspects, the percentages showing naïve, mixed and informed views differ by less than 15%, suggesting doubts and confusion amongst learners regarding the possibility that there may be different interpretations, challenging the often-presumed exactness of science.

Discussion

Overall, the learners in the STEM school revealed good understanding about NOSI. We ascribe this to the STEM focus of the school. The aspect *multiple methods* was least understood by the sampled learners. This may be due to the textbook used by the physical science teachers in the STEM school. The opening chapter of the textbook starts with the following heading and paragraph:

> *Identify an investigative question and formulate a hypothesis*
> Scientists have a certain agreed way of doing research. In order for their work to be recognized and accepted by other scientists, they must follow the **scientific method.** We will use a simple version of the scientific methods to learn how to conduct proper investigations in Physical Science … We start by formulating an investigative question and a hypothesis (Broster et al., 2013, p.12).

The idea of a single scientific method may be encouraged amongst learners (and teachers) by the singular form “the scientific method”, despite the plural form appearing in the next line of the question. This could explain the relatively poor understanding of the aspect *multiple* *methods*. At the same time the quote may promote understanding about the importance of a scientific question, reflected in the well understood aspects.

The STEM school's participation in the annual Eskom Expo for Young Scientists may also enhance understandings of the scientific inquiry aspects identified above. For example, one participant with a naïve view about *multiple methods* referred to the "template" in the Expo Project Guide Book which he liked to use, where the template stipulates that the independent, dependent and controlled variables need to be specified for an investigation.

The data from the STEM school were compared to that from a study by Penn and Ramnarain (2021) involving a group of six schools from Johannesburg in South Africa. The group included schools across the socioeconomic spectrum and did not focus on STEM in particular. Figure 1 reveals that the STEM school displayed overall better understanding than the Johannesburg schools. We speculate that this can be explained by the support received in the STEM school, while the learners in the Johannesburg were not exposed to any planned inquiry-based learning instruction (Penn & Ramnarain, 2021).

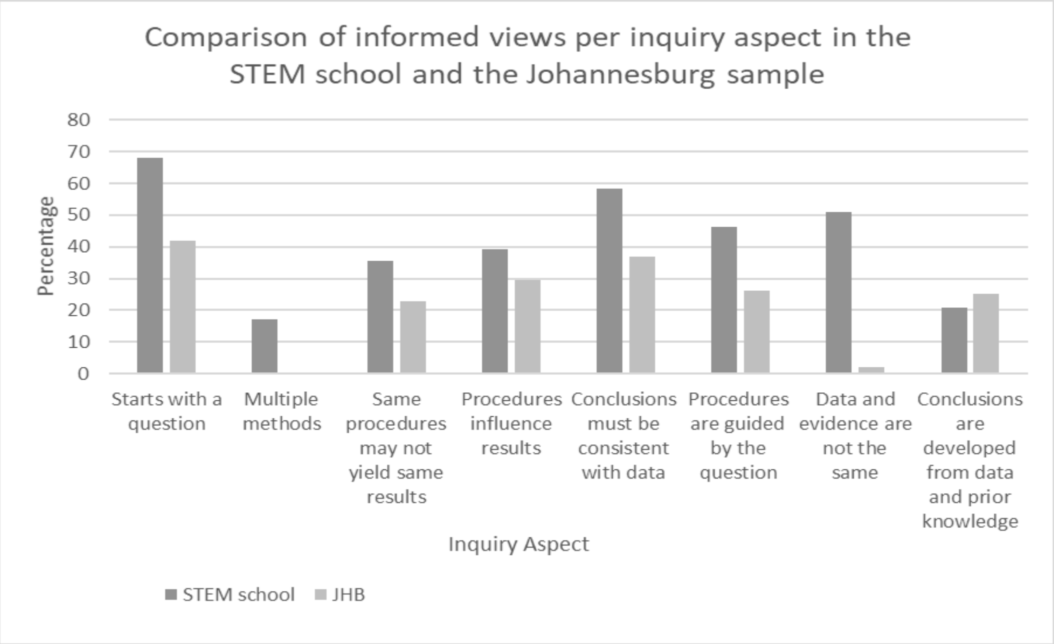

Figure 1. NOSI understanding amongst Grade 12 South African learners in a STEM supported school compared to unsupported public schools in the Johannesburg region (Penn & Ramnarain, 2021).

Figure 1 indicates three striking findings with regards to the difference in NOSI between the STEM supported and unsupported schools. First, the understanding of the aspect *data and evidence are not the same* has been very strong in the STEM school compared to the unsupported schools in Johannesburg. It is speculated that during the preparation and assessment of the investigation projects learners are often asked by their teachers and Expo judges questions like 'what do your data tell you?' Interviews conducted by judges with all learners about their investigation projects are compulsory in the Eskom Expo for Young Scientists (Eskom Expo, 2020).

Second, understanding of the aspect *conclusions are developed from data and prior knowledge* is unusual in that it is less strong in the STEM school than in the unsupported Johannesburg schools. One may speculate that the continuous focus in Dinaledi schools on performance and examination results to justify the extra support, laboratory work is more confirmatory in nature. Consequently, it seems that the perception that is cultivated is that there is only one correct approach of getting the conclusions, making the data the sole source of evidence.

Third, the poorest understood SI aspect in both cases is *multiple* methods with the STEM school having 17.3% informed answers and the Johannesburg region 0.5%. The result is not surprising for the Johannesburg schools, as no planned inquiry-based learning instruction is done in these schools as mentioned above. What seems to emerge here is that within the STEM school the topic of multiple scientific methods had not been addressed explicitly by teachers or experienced by learners when doing practical work related to experiments and/or scientific observations in science teaching laboratories or during participation in the science fair Eskom Expo for Young Scientists. In fact, the excerpts above from the textbook's introduction referring to 'the scientific method', and the 'template' from the Expo Project Guide Book may reinforce the idea of one single acceptable method amongst learners and teachers. Consequently, it is possible that teachers adopt the habit of referring to '*the* scientific method' which may further reinforce this belief.

Conclusion

Overall, the Grade 12 learners from the STEM school have well informed views of NOSI as compared to the Johannesburg group. These results might be explained in terms of the STEM focus of the school, where repeated encounters with ideas about scientific inquiry can shape images of science, resulting in a repertoire of ideas about science rather than a uniform view (Bell & Linn, 2002).

However, this understanding is nonuniform across the eight aspects of NOSI. Two aspects, *multiple methods,* and *conclusions are developed from data and prior knowledge,* are poorly understood. It is possible that an emphasis on a scientifically acceptable presentation of the xpo science projects in the STEM school may encourage viewing scientific inquiry as a rigid process. It appears that the role of human creativity in interpretation may be overlooked while presenting a view that science is simply data based, external and independent of the human mind and previous knowledge. Learners in the STEM supported school may therefore become more rigid in their thinking about some aspects of scientific inquiry as an unintended consequence of scientific correctness and exactness promoted by the school.

However, not only in the STEM school, but also in the Johannesburg group and the world Grade 12 study *(*Lederman et al., 2021), the aspect understood most poorly was *multiple methods*. It seems that learners are for the most part exposed to the practice of experimentation and hypothesis testing and this becomes conflated into the idea of a monolithic scientific method. School-based curricula in chemistry, physics and life science/biology do not strongly convince learners that there are sciences, mostly historical in nature, that rarely use experiments to test their hypotheses. Such sciences include for example palaeontology, astronomy, earth science and much of evolutionary biology which are often field-based and empirical but not experimental.

What seems limited or even absent is instruction on scientific inquiry that engages learners in reflections upon what they did in different kinds of investigations and the implications and that this indicate that scientists may also use different methods during their investigations. Consequently, a result is a lack of appreciation for the role of the creative human mind in producing scientific knowledge and may lead to a belief that knowledge about an external world can be isolated from the human mind. We therefore recommend that more research be conducted into how learners (and others) understand the role of human creativity in SI.

Disclosure Statement

The authors declare that we had no competing financial interests with regard to the research reported in this article.

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