Knowledge about Inquiry: A Study in South African High Schools

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This paper reports a study on South African learners' knowledge about scientific inquiry using the Views About Scientific Inquiry (VASI) questionnaire. The sample consisted of 105 grade 11 learners from 7 schools across the socio-economic spectrum in a South African city. A rubric for scoring the VASI questionnaire was developed and refined during the process of coding and is presented. Results showed that the learners held more informed views than that reported in previous international studies, except for particularly naive views regarding multiple methods of investigation. The results are discussed in terms of the Revised National Curriculum Statement (RNCS) that was taught from 2003 to 2010 in South African schools. This curriculum was founded on outcomes based principles, valuing process skills rather than content. The study found that examples provided in the RNCS document correspond closely to the aspects of inquiry as described by the National Research Council (NRC). It is argued that the RNCS contributed to the more informed views about inquiry found amongst South African learners in this study.

Key words: Scientific Inquiry, Scientific Literacy, Science Curriculum, Views about Inquiry

Introduction

The use of the term inquiry in science education dates back to the middle of the 19th century. Ever since, the term became central to reforms in science education and its meaning broadened to accommodate various perspectives (Bybee, 2000; de Boer, 2004). Anderson (2007, p.808) describes inquiry as both a 'catch phrase' and a 'useful label' to 'integrate many facets of educational practice'. In a broad sense, scientific inquiry represents the systematic processes of investigating questions about the natural world, leading to the discovery and establishment of new scientific knowledge.

In school curricula, scientific inquiry is essential to the development of future generations of scientists, as well as to the development of a scientific literate population (Driver, Leach, Millar & Scott, 1996; N. Lederman, Antink & Bartos, 2012; Millar, 2006; Millar & Osborne, 1998). Scientific literacy requires an understanding of the nature and the processes of science. These understandings are closely related but described separately by the National Research Council (NRC) as knowledge about scientific inquiry and nature of science (NRC, 1996). Some scholars argue that the processes of science are part of the nature of science and prefer an integrated approach (Allchin, 2011; Wong & Hodson, 2008). In this paper, we follow the separate approach accepted by the NRC and focus on understanding the processes of science in terms of knowledge about scientific inquiry amongst South African high school learners.

In South Africa (SA), the ideal of a scientifically literate population is one of the visions embraced by the young democracy since its inception in 1994 (Chisholm & Leyendecker, 2008). This ideal is reflected by an emphasis on scientific investigations in the reform curricula (Department of Education [DOE], 1997; 2002). Following the educational reforms, some research on scientific investigations was undertaken in SA (Dudu & Vhurumuku, 2012; Hattingh, Aldous & Rogan 2007; Ramnarain, 2010; Rogan, 2004), showing that learners had limited exposure to doing inquiry. However, no research on knowledge *about* scientific inquiry amongst SA learners has been reported. The current paper aims to investigate this neglected aspect of scientific inquiry, to provide a baseline of knowledge *about* scientific inquiry amongst South African learners and to interpret results in terms of South African reform curricula. Such a baseline could inform South African policymakers and teacher educators in future planning towards developing learners' knowledge about inquiry. This may enhance scientific literacy in the young democracy, improve performance in science and ultimately contribute to address the shortage of scientists and engineers in the country.

What is scientific inquiry and how has it been situated in the US reforms?

Inquiry has grown in popularity in science education in the US since the cold war and has been explicitly promoted by the NRC (1996, 2000). The National Science Education Standards (NSES) describes inquiry as 'diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work (NRC, 1996, p.23). Different meanings are attached to inquiry in science education; these were described by the NRC (1996) as an engagement in the processes of inquiry, knowledge about the inquiry process, and teaching by inquiry**.** The New Generation Science Standards (NGSS) (Achieve, Inc., 2013) and the Framework for K-12 Science Education (the Framework) (NRC, 2012) give preference to the term 'science practices' rather than 'inquiry', thereby emphasizing that 'engaging in scientific inquiry requires coordination both of knowledge and skill simultaneously' (NRC, 2012, p. 41). The Framework points out that 'science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend and refine that knowledge' (p.26).

Research on inquiry is dominated by a focus on classroom based science investigations (Capps & Crawford, 2013; NRC, 2012). Chinn and Malhotra (2002) found that 'many scientific inquiry tasks given to students in schools do not reflect the core attributes of authentic scientific reasoning' (p.176), and suggest that inquiry tasks should go beyond hands-on activities to also include evaluation of evidence, complex data and simulations. Hofstein and Lunetta (2004) argue that laboratory activities should engage students in intellectual rather than simply physical investigations. The science practices promoted by the Framework (NRC, 2012) attempt to address these shortcomings, and it is therefore expected that the NGSS (Achieve, Inc., 2013) would contribute to achieve the goal of appropriate classroom-based inquiry.

Amidst the research focus on classroom-based inquiry, the development of knowledge about inquiry has received less attention (J. Lederman et al., 2014). The importance of knowledge about inquiry was noted by the Benchmarks for Science Literacy (American Association for the Advancement of Science [AAAS], 1993) advising that students should at least acquire knowledge about inquiry in order to be scientifically literate. In the same vein, the Framework (NRC, 2012) points out that '… … understanding of how science knowledge is produced …… will help students become more critical consumers of scientific information' (p.41). The National Science Education Standards (NSES) (NRC, 2000) identified eight essential aspects of knowledge about inquiry that should be known in a scientifically literate community. These eight aspects are implicitly contained in the scientific practices identified by the Framework (J. Lederman et al., 2014). According to the NSES (NRC, 2000), the essential aspects of knowledge about inquiry are:

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

Research emphasis has been on inquiry as action, implicitly assuming that by doing inquiry, students would automatically develop understanding of the inquiry process. However, there is growing evidence that implicit approaches do not deliver the expected understanding (Abd-El Khalick & Lederman, 2000; Bell, Blair, Crawford & Lederman, 2003; N. Lederman & J. Lederman, 2012; Schwartz, Lederman & Crawford, 2004; Metz, 2004). Instead, explicit instruction has been shown to support the development of knowledge about inquiry (Haefner & Zembal-Saul, 2004; Schwartz et al., 2004). While doing inquiry is restricted to activities that can be carried out in the classroom and the accessible environment, explicit teaching of knowledge about inquiry can transcend the boundaries of space and time while developing scientific literacy. For example, understanding how different explanations of the same data are possible in the case of the competing theories to explain the extinction of the dinosaurs, while a recent event such as the discovery of the Higgs boson illustrates the tentativeness of scientific knowledge.

A large-scale professional development project, called Inquiry, Context, and Nature of Science (ICAN) (J. Lederman, N. Lederman, Kim & Ko, 2012) included the development of the Views of Scientific Inquiry (VOSI) instrument to explore ideas about the way scientists work when they conduct investigations (Schwartz, N. Lederman & J. Lederman, 2008). This instrument was revised and expanded by J. Lederman, N. Lederman, Bartos, Bartels, Antink, and Schwartz (2014) to develop a new questionnaire, the Views About Scientific Inquiry (VASI), which addresses the eight aspects of inquiry proposed by the NRC (2000). The VOSI and VASI questionnaires consist of various open ended questions suitable for teachers as well as for learners of different ages. These instruments were applied to large groups participating in the ICAN project, revealing that prior to explicit instruction, learners performed very poorly (J. Lederman et al., 2012). For example the best known aspect of inquiry was ‘conclusion in agreement with data’ for which the average pre-test occurrence of informed views was a mere 26% in the VASI (J. Lederman et al., 2014).

Curriculum reforms in South Africa

Before the political transformation of 1994, education in SA has been segregated on racial lines, with separate departments of education, curricula and funding for different racial groups (Hartshorne, 1992). After democracy was attained in 1994, the education system has seen many changes to undo the damages of racial discrimination (Chisholm & Leyendecker, 2008). These changes included a series of drastic changes to curricula, of which the introduction of Curriculum 2005 (C2005) in 1998 was the first. This was an ambitious effort to eliminate rote learning of content which characterized education prior to the democratization of SA (Department of Education [DOE], 1997). The new curriculum introduced Outcomes Based Education (OBE), based on Spady's (1994) vision that outcomes be focussed on higher levels of skills and life performance roles rather than on learning prescribed content. In fact, C2005 did not prescribe any content, expecting of teachers to develop their own learning materials suitable for their situations. Ironically, this ideal was particularly difficult to achieve in previously disadvantaged schools where resources were lacking and teachers were poorly trained (Jansen, 1999). Consequently, C2005 did not succeed to improve the quality of education for the disadvantaged majority for whom it was meant to secure a better future. Furthermore, the short timeframe of introducing the curriculum change and the complex curriculum design resulted in implementation problems and severe criticism, leading to an early revision of C2005 (Chisholm, 2000).

Following the failure of C2005, a second generation of reform curricula was developed. The Revised National Curriculum Statement (RNCS), for preschool to grade 9, was introduced in 2003 (DOE, 2002) and the new high school curriculum, the National Curriculum Statement (NCS), followed in 2006 (DOE, 2008) for grade 10-12. Although the RNCS and NCS did prescribe some content, the outcomes based principles and focus on skills envisaged in C2005 were retained. Consequently, the RNCS and NCS curricula were also criticized in the South African media for the lack of emphasis on content. In fact it was blamed for learners' poor performance in final school examinations (Pretoria News, 2009; Sunday Times, 2009) and international achievement tests such as TIMSS (Martin, Mullis, Gonzales & Chrostowski, 2004; Reddy, 2006; Reddy, Prinsloo, Visser, Arends, Winnaar, Rodgers, Janse Van Rensburg, Juan, Feza, & Mthethwa, 2012). The criticism resulted in the return to a content driven curriculum, eight years after the implementation of the RNCS. The third generation of curriculum reform, named the Curriculum and Assessment Policy Statement (CAPS) was introduced in 2011 (Department of Basic Education [DoBE], 2011).

This paper explores the views about inquiry amongst South African learners and the possibility that the RNCS shaped these views. The participants were in grade 11 during 2012 when data were collected. Most of them started grade 2 in 2003, the year when the RNCS was introduced in schools, and they started grade 10 in 2011, the year when the RNCS was replaced by the CAPS. These learners were therefore schooled within the RNCS for eight years prior to data collection. A comparison between the RNCS and the aspects of inquiry envisaged by the NSES was undertaken in the current study to ascertain to what extent the RNCS curriculum addressed knowledge about inquiry. Though the CAPS curriculum was introduced when the participants were in the grade 10 year, is not investigated in the current study as it is content focused and does not promote inquiry.

The RNCS specified three learning outcomes: outcome 1 was 'scientific investigations', outcome 2 was 'constructing scientific knowledge' and outcome 3 was 'science, society and the environment'. Scientific investigations was a priority, described as follows (DOE, 2002, p.6):

> The learner will be able to act confidently on curiosity about natural phenomena, and to investigate relationships and solve problems in scientific, technological and environmental contexts.

Besides the three learning outcomes of the RNCS, assessment standards were specified as policy to provide a 'common national framework for assessing the learner's progress' (p.46).

For example, the following assessment standards were specified for the senior phase (grades 7, 8 and 9):

- Planning investigations
- Conducting investigations and collecting data
- Evaluate data and communicating findings
- Recalling meaningful information when needed
- Categorising information to reduce complexity and look for patterns
- Interprets information
- Applies knowledge to problems that are not taught explicitly
- Understands science as a human endeavour in cultural contexts
- Understanding sustainable use of earth's resources

These assessment standards for scientific investigations resonate with the eight aspects of inquiry described by the NSES, and are outlined in detail in Table 1. The table also presents illustrative examples from the RNCS document, demonstrating the correspondence with the eight aspects of inquiry.

Research showed that the ideal of engaging in inquiry was not realized in typical South African schools. Rogan (2004) conducted a study in 12 disadvantaged schools that were participating in a professional development programme and found that learners had no opportunities to design investigations as envisaged by the curriculum, and they were not even participating in laboratory activities. Amongst well-resourced schools, Ramnarain (2010) found that teachers seldom allow complete learner control during practical activities despite the curriculum requirements. Dudu and Vhurumuku's results in well-performing schools indicated that teachers prefer controlled investigations to open investigations (2012). Mji and Makgatho (2006) found that laboratory activities were mostly aimed at confirming existing theory. The literature thus indicates that South African learners across the socio-economic spectrum have little exposure to doing authentic inquiry in schools. Regarding knowledge about inquiry in SA, no studies about learners were thus far reported, but a recent study involving five teachers indicated that their understandings were 'fluid' and it 'lacked coherence' (Dudu, 2014, p.15). The current study explores this neglected aspect of knowledge about scientific inquiry amongst learners, and interprets results in terms of the RNCS.

Data collection and analysis

The VASI questionnaire (J. Lederman et al., 2014) was utilized to establish a baseline of South African learners' knowledge about scientific inquiry. The questionnaire, given in the appendix, contains contextualized questions based on the different aspects of inquiry as described by the NSES.

The sample was drawn from seven schools in one of the large cities in SA. The selection was purposeful to include schools across the socio-economic spectrum and based on accessibility to the researcher. There was one elite private school with many with learners from wealthy

Table 1. Correspondence between the RNCS for Gr 7-9 and the Aspects of Inquiry

Inquiry Aspect	Curriculum document (RNCS, 2002)		
	Assessment Standard	Illustrative Example from the RNCS	Grade -Page
Begins with question	Plans investigations	Identifies a testable *question* among a set of possible questions	7- 48
		Modifies a vague *question* to make it testable	8-49
		Expresses a *question* in a testable form	9-49
Multiple methods	Plans investigations	Plans simple *tests and comparisons*, and considers how to make them fair.	7-48
		Plans a *procedure* to test predictions or hypothesis, with control of an interfering variable*	9-49
		Pilot test an *interview* schedule before doing a *survey*.	9-49
Procedure guided by question	Conducts investigations and collects data.	Collects and records information as accurately as equipment permits and investigation *purposes require*.	8-49
	Evaluates data and communicates findings.	Describes how the plan and data collection procedure was checked against the *focus question.*	8-51
Same procedure, different result	Understands science as a human endeavour.	Compares differing *interpretations* of events.	7-58
		Identifies and explains differences in two reports of the *same* event or *investigation.*	7-58
Different procedure, different result	Conducts investigations and collects data.	Modifies *procedure* to obtain better observations or readings#	7-48
		Reviews data collecting *procedures* during the *investigation#*.	8-49
Conclusions consistent with data	Evaluates data and communicates findings.	Generalises in terms of a relevant aspect and describes how the *data* supports the generalisation[$]	7-50
	Conducts investigations and collects data.	Discuss the *meaning of the data* being collected, comparing them with the focus question[$].	9-49
Data differs from evidence	Evaluates data and communicates findings.	Generalises in terms of a relevant aspect and describes how the *data supports* the generalisation[$]	7-50
		Offers a strong example of *evidence* that support the findings.	7 -50
		Lists items of *evidence* supporting the finding.	8-51
Explanations developed from data and existing knowledge	Conducts investigations and collects data.	Compares information from *other sources* when different views are likely or important.	9-49
	Evaluates data and communicates findings	Considers the extent to which the conclusions reached are *reasonable answers* to the focus question of the investigation.	8-51
	Interprets information	Studies photographs of fossil animals and *make inferences* about their ways of feeding and moving	8-55

*May reinforce idea that all investigations should be experimental.

[#] May reinforce idea that there is only ‘one correct way’ leading to ‘the correct’ result.

[$] May reinforce idea that data and evidence is the same.

families, two middleclass suburban schools where parents were mostly professionals, three city schools with learners from low-income families and one school drawing learners from a poor informal settlement where most parents were unemployed and many learners were orphans living with family or neighbours. Science teachers were requested to conveniently select one grade 11 class from their school. The questionnaire was administered early in the academic year. The number of returned questionnaires varied from 15 to 42 across the schools, as a result of differing class sizes and learners' willingness to participate. Fifteen questionnaires per school were randomly selected for analysis, amounting to a sample of 105 learners in total.

Responses were classified reflecting informed, mixed, or naive understanding of the eight aspects of inquiry. Five experienced US researchers initially worked together with a researcher from SA to establish inter-rater reliability. Questionnaires were coded individually by all group members and discussed to reach consensus. After four coding sessions, 80% agreement was achieved, and thereafter the bulk of coding was done by the first author. Problematic cases were referred back to the group members and discussed to reach consensus. A scoring rubric was developed during the coding process and is presented in Table 2. Each of the VASI questions targeted a specific aspect of inquiry, indicated in the Table 2. Occasionally, answers revealed information about more than one inquiry aspect, which was then taken into account in coding the relevant aspect.

Table 2: Rubric for scoring the VASI questionnaire

Question nr. & Inquiry Aspect	Informed	Mixed	Naïve
1a,b & c Scientific investigations can follow different methods.	All 3 answers must be appropriate. 1a: Yes, the investigation is scientific as it aims to explain some aspect of the natural world. 1b: No, it is not an experiment as there is no manipulation / control of variables / testing. 1c: Yes, investigations can follow different methods: experimental / practical / testing as opposed to non-intrusive / non-experimental / research/ investigation / observation / theoretical/ not-practical. Two suitable examples required: one experimental and the other non-experimental.	No more than 1 of the following types of mistakes: 1b: yes, it is an experiment Or 1c: one general method Or 1c: both examples are experimental Or 1c: both examples are non-experimental	1c: Only one scientific method; Or any two/more mistakes eg: 1b: yes, experimental, and 1c: similar examples.
2 A scientific investigation should begin with a question, not necessarily a hypothesis.	A question is the fundamental reason why an investigation is undertaken, a driving force.	A question is useful, but is regarded as part of a formal structure, investigation may be undertaken first and questions formulated later.	Investigation should start with a hypothesis; Also questions are not essential.

3a All scientists performing the same procedures may not get the same results.	The human factor may cause different interpretations of similar data, leading to different results.	Imperfect experimental conditions may lead to different results.	Similar procedures would always lead to the same results.
3b Procedures of investigations can influence results.	Different procedures would yield different datasets which would lead to different results.	Different results would be primarily caused by the different interpretations.	Only one result is possible regardless of the procedure.
4 Data are not the same as scientific evidence.	Evidence is generated from data, to support a claim/ conclusion.	Evidence differs from data; unclear/wrong/no explanation.	There is no difference between data and evidence.
5 Question drives the process.	A did the best experiment because they addressed the proposed question. Or, both experiments are inadequate as the best tire on one surface may be worst on another.	A did better, no explanation / argues that the tire has a larger effect than road. Or, B did better, argues that the road has a larger effect than tire.	Team B did better, illogical or no explanation
6 Conclusions should be consistent with data collected.	Option (b) is correct, i.e. ‘plants grow taller with less sunlight’ because the data showed such a trend. Speculations about the ‘unusual’ data is acceptable provided option (b) is chosen.	Option (c) is correct, i.e. ‘growth not related to sunlight’ with an explanation. Or, option (b) without explaining.	Option (a) is correct, with or without an explanation. Or, option (c) with no or illogical explaining.
7a & b Explanations must be based on data and existing scientific knowledge.	Three relevant ideas: Two reasons: Function of larger hind legs/ comparison with existing models of dinosaurs/ fitting of joints. One information type: Existing knowledge of dinosaurs/ skeletons/ joints.	Only two relevant ideas.	One or no relevant ideas.

Results

Figure 1 represents the number of participants found to have informed, mixed and naive views across the eight aspects of inquiry. The outstanding result is that the SA learners displayed understanding similar to that obtained *after* explicit instruction in international studies (J. Lederman et al., 2014; J. Lederman et al., 2012). For example, the best known aspect, ‘agreement between conclusions and data’, yielded 60 % informed views compared to 26% in pre-test and 66 % in post-test scores in the ICAN project (J. Lederman et al., 2014). Poorest understood amongst the SA sample is the aspect ‘multiple methods of science’, for which 43.8 % of students displayed naive views.

Figure 1. Knowledge about the eight aspects of inquiry amongst South African gr. 11 learners (N=105)

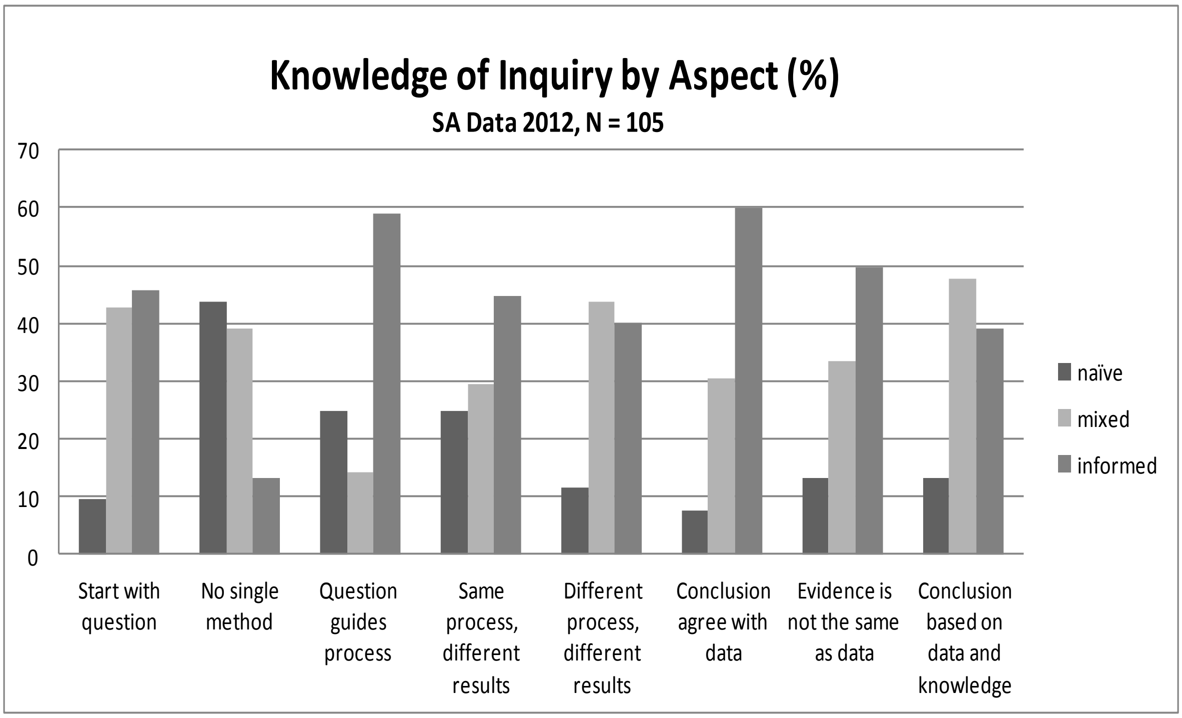
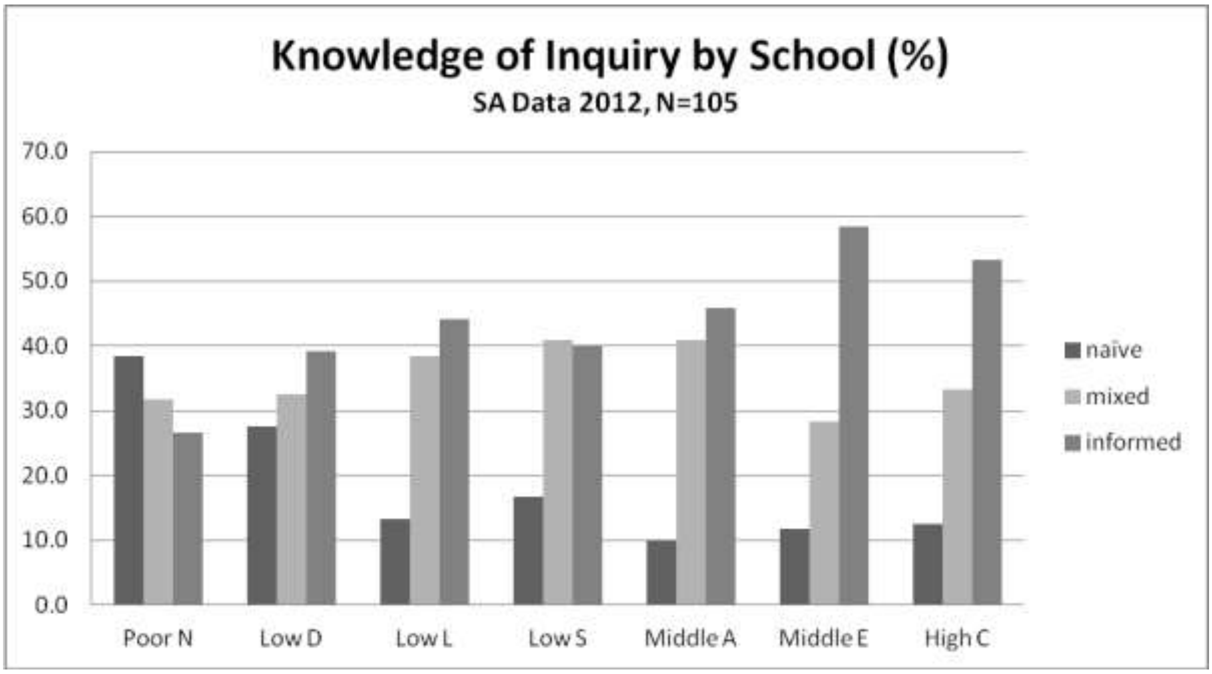


Figure 2. Knowledge about inquiry averaged over eight aspects according to school and SES (N=105).



The distribution of informed, mixed and naive views were also analysed per school. Figure 2 shows percentages of informed, mixed, and naive views averaged over the eight inquiry aspects per school. The schools were coded A, C, D, E, L, N and S to protect anonymity while the socio-economic status (SES) of each school is indicated as high, middle, low and poor: high C represents an elite private school of a high SES; middle E and middle A represent the two middle class schools; low S, low D and low L represent the three low SES schools while poor N represents the school from a poverty ridden community. Figure 2 shows a general tendency towards more informed views and less naive views for schools with a higher SES. In fact, the school N, located in an impoverished community, displayed the highest naive count together with the lowest informed count, in agreement with Jansen's prediction (1999) that OBE would not benefit the disadvantaged majority in SA.

Responses to questions are discussed below and examples of responses are provided in table 3. In order to protect anonymity, each learner is referred to by a combination of the school code and a number.

Question 1

Question 1 probes understanding that scientific investigations can follow different methods, i.e. there is no 'one scientific method'. Many students were unable to distinguish between experiments and investigations, claiming that the study about the birds was experimental in question 1b, yet distinguishing two types of investigations when answering 1c. In contrast, others showed a clear understanding of the difference between experiment and investigation in 1b, while the response to question 1c indicated a belief that scientific investigations should follow one method. For this question, most of the responses were coded naive. The most common type of naive response claimed that the bird investigation was an experiment and that there is only one acceptable way to investigate. The learners seldom used the term 'scientific method' in their answers, even when claiming that only one method of investigation is acceptable. During the coding process it also became clear that the meaning of the word 'experiment' was unclear to many learners who described any data collection procedure as an 'experiment'. Sometimes learners referred to 'practical' or 'testing' to describe experiments, and 'investigations', 'observations', 'theoretical', 'research' and 'not-practical' to describe non-invasive studies.

Question 2

Question 2 targets understanding that a scientific investigation should begin with a question, but not necessarily a hypothesis. In some cases, responses to question 1a confirmed the answers given in 2, by referring to a question as the hallmark of a scientific investigation. Few of the responses to question 2 referred to a hypothesis, but since the question did not specifically refer to a hypothesis, it was not possible to conclude what learners' understanding about the role of a hypothesis was. The naive count was very low (9.5%), indicating that learners were well aware that investigations are based on questions. However, the mixed responses were almost as many as the informed ones, indicating that many learners do not regard a question as an essential starting point. Instead it is often regarded as part of a formal procedure, as if a scientist first decides to do an investigation and then formulates the question.

Table 3. Examples of students' answers representing informed, mixed and naïve views in the VASI questionnaire

Question nr	**Informed**	**Mixed**	**Naïve**
1	Student A2: a) Yes, research is done to gain knowledge. Yet it cannot be proved until an experiment is conducted in a controlled environment. b) No, so far it is only an investigation, for it to be an experiment it must be in a controlled environment. c) Yes; the traditional hypothesis and answer design and an experiment is done in a controlled environment; research that is done in the field in the natural habitat.	Student C14: a) Yes, because there was a scientific question, hypothesis, data collected and a conclusion made at the end. b) Yes, because the person wanted to get to a conclusion and watched different birds eating different foods to get data. c) Yes. Watching the outcome of biological beings, conducting an experiment in a lab with set variables and controls. Student C1: a) Yes a) because the shape and dimensions of the beak could relate to the shape dimensions and texture of the beak [food?]. b) No because he made an observation he did not set anything up to find this information. It is something he researched not experimented. c) No, scientific investigations generally have one layout.	Student D10: a) Yes the shape of a birds' beak relates to the type of food it eats, for example birds that eat nuts need a strong, short beak to crack the nuts open. And birds that eat insects need long beaks to reach the insect's hole etc they do not need hard ones because insects are soft bodied. b) Yes he needs to collect data before he could conclude the shape of a bird's beak and the type of food it eats. c) No, all scientific investigations should contain a scientific question hypothesis, apparatus, practical investigation, results and conclusion Student L6: a) No there are no values and calculations to prove it is scientific. b) No, there is nothing relating to science that is measured or evaluated. No, there is only one way to conduct a scientific investigation is by doing calculations and evaluating the statistics.
2	Student L14: I agree with the student who said yes. You have to be able to know analyse first what you are looking for or what you are trying to find out.	Student C19: I would say yes. The scientific question explains why the experiment needs to be done and can help guide the scientist in the right direction.	Student A9: The student who says no, you can study something in general and obtain results in this way.
3a	Student L13: No. Though they ask the same question & follow the same procedure it doesn't necessarily mean that they'll have the same conclusion. This is because they have different mindset and ways of analysing things.	Student E1: No, their results may differ because something may have leaked etc which would affect the conclusions of the experiment.	Student C14: Yes, the outcomes of the experiments are accurate and are to discover the truth of what really happens therefore the same thing will happen every time.

3b	Student S5 : No, because the manner in which they have collected the data may cause a variation in the results.	Student C14: No, one of the procedures could have had uncontrolled variables or data could not have been recorded accurately.	Student E6: Yes in science most things are linked and in reality there is always more than one route to get to the same destination.
4	Student C2: Data is raw information that has been found or gathered. Evidence, however, is the manipulation of the data to prove or support a theory (by looking at trends etc.)	Student E5: Data is something one has gone out and gotten (such as amounts etc) then can be used. Evidence is something that is already present no need to go and retrieve it, just to analyse/use.	Student L27: No, data and evidence are similar because you get or find it.
5	Student E6: It is testing for the relevant issue which is if certain brands of tires are more likely to get flat and not if the roads are the reason for flat tires. Student C42: Neither are better than the other. They both are badly thought out. Team A covers the aspect on the brand of tire. Team B covers the different road surfaces. For the experiment to be proper the teams need to test both aspects and combine their two experiments.	Student N13: The team B’s procedure is better than the other one because they used one tire brand on three types of road surfaces to make sure that this tire is suitable on those three types of road rather than using various tires on one type of road surface, cause this tire can be suitable on that type of road surfaces but what about the other type of road surfaces, it won’t be easy.	Student D 32: Team B is better than team A because they are testing three types of road surfaces using one tire. This even makes them to save more money than buying three tires for the experiment.
6	Student C2: When there was no sunlight plants grew the most and when there was a lot the plants never grew at all. Student E7: Too much sunlight or the more sunlight, the less the plants grew, the less sunlight the more the plants grew. Plants need sunlight to make food and too much of it can possibly dry out the leaf and there won’t be enough water for the plant to survive.	Student S5: Even though it may seem that there is a pattern, the one plant only grew 10 cm despite being in the sun for 20 min.	Student N19: Because it shows that the plant has enough photosynthesis.
7	Student E9: a) The animal in figure 1 resembles an animal that has proof from previous fossils. Fig. 2 is out of proportion as its front legs are larger than its hind legs which is not suitable for survival. b) Previous research; understanding of animal survival, basic bone structures of animals, the use of each structure.	Student A13: a) A dinosaur known as T Rex has big tall strong back legs and short front legs that look like arms. That means that figure 1 is correct. b) What other scientists have gathered.	Student N13: a) Is because of the bones of it are balanced by having long bones on the legs. b) They conclude by conducting a scientific investigation.

Question 3a

Question 3a assesses understanding that scientists may come to different conclusions even when performing the same procedures due to the role of human interpretation. Responses representing mixed and naive views did not acknowledge that the human factor influences interpretations and shape conclusions. The naive responses typically argued that similar procedures would always lead to the same results. While 44.8% of responses were coded informed, the naive count was relatively high at 24.8%, indicating a belief that science is completely objective.

Question 3b

While the previous question focuses on interpretation of results, this question targets understanding that procedures can influence results, even when the same question is investigated. The naive count was quite low at 11.4%. This indicates that few learners believe in a single correct answer to a scientific question. Yet the mixed count was the highest (43.8%), indicating that learners do not ascribe different results to the human factor shaping the design of the investigation.

Question 4

Question 4 assesses the understanding that evidence differs from data, in the sense that evidence is a human interpretation of data, supporting a specific argument. About half of the responses (49.5%) were informed, with a small naive count of 13.3%. Learners were reasonably well informed on this aspect of scientific inquiry.

Question 5

Question 5 assesses understanding of the inquiry aspect ‘question guides the process’ with many learners (59.1%) demonstrating informed views. A few responses were going beyond the expected. These students showed a critical attitude, arguing that both experiments described in the question had shortcomings, as the road surface may influence tire performance. Such responses were also classified informed. Some learners did not focus on the given investigative question, instead arguing that the road surface may have more influence on a tire’s lifetime than the brand of the tire. It is also possible that students did not read the question properly, and reflected on the ‘best question’ instead of the ‘best procedure for the given question’.

Question 6

Question 6 probes the understanding that conclusions should be consistent with data collected. A dataset was provided, contradicting existing knowledge about photosynthesis. The learners were required to indicate which conclusion can be made from the given dataset. This question drew the most informed responses, with 60% of learners choosing the correct option, and justifying their choice from the dataset. Some learners also speculated about the unexpected behaviour of the plants in response to the question ‘please explain your choice’. There were only a small number (7.6%) of naive answers. These learners ignored the given data, choosing 'taller with more sunlight' based on prior knowledge rather than on the given dataset.

Question 7

Question 7 probes the understanding that explanations must combine data and existing scientific knowledge. Learners' answers were seldom well organized to separate the specific reasons required in (a) from the generalizations in (b). It also seems that the students did not fully understand what was meant by 'types' of information in question (b). Consequently, we accepted different specific 'types' of existing knowledge, for example 'knowledge about fossils'. This aspect of inquiry was not well understood, with most responses rated mixed (47.6%). Most answers referred to strong legs, balance and current knowledge about dinosaurs; few responses included the fitting of joints. It is possible that learners viewed the question within a modern context, where dinosaur toys and images are common, rather than in a historical context where a prototype was not available.

Discussion

For this study, the best understood aspect of inquiry was that conclusions should be in agreement with data, demonstrated by an informed count of 60 %, combined with the lowest naive count (7.6%) for question 6. However not all the learners with informed views understand that conclusions should also be in agreement with existing knowledge, as for question 7, most students (47.6%) had mixed views. The multiple methods of science was the poorest understood aspect of inquiry, where 43.8 % of learners showed naive views in question1, indicating the view that all investigations are experimental and should follow a specific method. Similar results have been reported in other studies (Bell et al., 2003). The role of investigative questions was reasonably well understood as found from the responses to questions 2 and 5. For question 5, most learners had informed views where 59.1 % indicated that the question must guide the process. However, not all these learners understood that questions actually start investigations, as for question 2, only 45.7% showed informed views. The role of the human mind in investigations was not clearly understood, resulting in questions 3a, 3b and 4 answered in somewhat conflicting ways. In question 4, most learners (49.5%) understood that evidence entails an interpretation of data. Mixed and naive views were noticeably less, indicating an understanding that the human mind gives meaning to data. Similarly, in question 3a, the majority (44.8%) indicated that different investigators may come to different conclusion even when following the same procedures. However, the relatively high naive count (24.8%) indicate that many learners do not acknowledge the effect of interpretation on conclusions. There was a different trend in question 3b, where mixed views (43.8%) were slightly more than informed views. This seems to indicate that many learners do not appreciate the human role in designing the research procedure, which may lead to different results.

The SA learners generally scored higher on the VASI questionnaire when compared to the pre-test scores of learners tested in other studies which employed the VASI (J. Lederman et al., 2014) and VOSI instruments (J. Lederman, et al., 2012). In fact, the SA scores are similar to the post- test scores achieved after explicit instruction in these studies. This is a surprising result as the current study was a baseline study, and it was expected to obtain results similar to pre-test scores recorded in other studies. We propose that the SA learners' higher scores can be attributed to the reform oriented curriculum, the RNCS, which was taught during the years when the learners were in grade 2 to 9. This argument is supported by similarities found between the examples provided in the RNCS document and the eight aspects of inquiry, summarized in Table 1. This correspondence indicates that the RNCS expected SA learners to acquire knowledge about investigations similar to the knowledge about inquiry envisaged in the USA by the NSES.

While poor understanding of the multiple methods of scientific investigation is also reported in other studies, the RNCS may have contributed to poor understanding of this aspect of inquiry found in the current study. Many learners were not familiar with the meaning of the word ‘experiment’ which may relate to the fact that this word is not used in the RNCS document. Instead, ‘test’ and ‘investigation’ are used. Furthermore, six examples of investigations referring to testing compared to only one example based on a survey, can be found in the RNCS examples given in table 1. This imbalance may have contributed to a belief that all investigations involve testing. We therefore propose that prominence given to studies involving testing in the RNCS document contributed to the SA learners’ poor understanding of the multiple methods of scientific investigation.

It is emphasized that the results of the current study should be interpreted in the context of the RNCS curriculum and not be generalized to learners schooled under another curriculum, particularly the newly introduced CAPS. Also, the results do not apply to all SA secondary learners as our sample consisted of grade 11 learners, excluding grades 8 and 9 learners for whom science is a compulsory subject. The grade 11 learners, having chosen science as an elective subject, are probably more interested in science which may favour more informed views.

Our study originally aimed to establish a baseline of learners’ knowledge about scientific inquiry and therefore the data collected do not provide information about how this understanding developed. It was a surprising result to find that SA learners are reasonably well informed in the light of previous evidence that that inquiry activities seldom occur in SA schools (Dudu & Vhurumuku, 2012; Hattingh, Aldous & Rogan 2007; Mji & Makgatho, 2006; Ramnarain, 2010; Rogan, 2004). However, the result should not be regarded as an complete anomality as the literature reports that knowledge about inquiry does *not* develop through engaging in investigations but rather through explicit reflective instruction (Bell et al., 2003; Abd-El-Khalick & Lederman, 2000). It is therefore possible that learners may develop informed views about inquiry should a teacher facilitate explicit reflective discussions without learner engagement in inquiry activities. We believe that the prominence of statements about the nature of scientific inquiry in the RNCS may have prompted many SA teachers to engage learners in explicit reflective discussions, in an attempt to teach the curriculum. If this is the case, our result can be explained in terms of learners’ engagement in explicit reflective activities even though they may not have had opportunities to undertake investigations themselves.

The results of our study have important implications for the development of scientific literacy worldwide. While authentic inquiry remains an ideal of science education, the achievement of informed views about the nature of scientific inquiry may be a realistic target in poorly resourced contexts. Research on how knowledge about inquiry actually develops in classrooms should be undertaken, and the effects of an explicit reflective approach may be of particular interest. For the South African science education community, the recent discontinuation of the RNCS may negatively impact the development of knowledge about scientific inquiry in future years. More research should be undertaken to understand SA teachers' views about inquiry as well as their teaching of the nature of scientific inquiry.

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Appendix

Views about Scientific Inquiry Questionnaire

The following questions are asking for your views related to science and scientific investigations. There are no right or wrong answers.

1. A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds that 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 that 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.

2. 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?

3. (a) If several scientists ask the ***same question*** and follow the ***same procedures*** to collect data, will they necessarily come to the *same conclusions*? Explain why or why not.
    (b) If several scientists ask the ***same question*** and follow ***different procedures*** to collect data, will they necessarily come to the same conclusions? Explain why or why not.

4. Please explain if “data” and “evidence” are different from one another.

5. Two teams of scientists are walking to their lab one day and they saw a car pulled over with a flat tire. They all wondered, “Are certain brands of tires more likely to get a flat?”
    Team A went back to the lab and tested various tires’ performance on one type of road surfaces.
    Team B went back to the lab and tested one tire brand on three types of road surfaces.
    Explain why one team’s procedure is better than the other one.

6. The data table below shows the relationship between plant growth in a week and the number of minutes of light received each day.

Minutes of light each day	**Plant growth-height (cm per week)**
0	25
5	20
10	15
15	5
20	10
25	0

Given this data, explain which one of the following conclusions you agree with and why.
Please circle one:

a) Plants grow taller with **more** sunlight.
b) Plants grow taller with **less** sunlight.
c) The growth of plants is **unrelated** to sunlight.

Please explain your choice of a, b, or c below:

7. The fossilized bones of a dinosaur have been found by a group of scientists. Two different arrangements for the skeleton are developed as shown below.

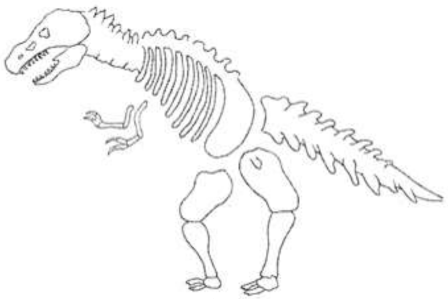

Figure 1

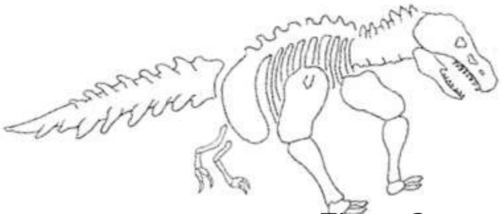

Figure 2

a. Describe at least two reasons why you think most of the scientists agree that the animal in *figure 1* had the best sorting and positioning of the bones?

b. Thinking about your answer to the question above, what types of information do scientists use to explain their conclusions?