International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

Consistency of nature of science views across scientific and socio-scientific contexts

Rola Khishfe

To cite this article: Rola Khishfe (2017): Consistency of nature of science views across scientific and socio-scientific contexts, International Journal of Science Education, DOI: 10.1080/09500693.2017.1287976

To link to this article: http://dx.doi.org/10.1080/09500693.2017.1287976

Published online: 20 Feb 2017.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2017
http://dx.doi.org/10.1080/09500693.2017.1287976

Routledge
Taylor & Francis Group

Consistency of nature of science views across scientific and socio-scientific contexts

Rola Khishfe

Department of Education, American University of Beirut, Beirut, Lebanon

ABSTRACT
The purpose of the investigation was to investigate the consistency of NOS views among high school students across different scientific and socio-scientific contexts. A total of 261 high school students from eight different schools in Lebanon participated in the investigation. The schools were selected based on different geographical areas in Lebanon and the principals' consent to participate in the study. The investigation used a qualitative design to compare the responses of students across different contexts/topics. All the participants completed a five-item open-ended questionnaire, which includes five topics addressing scientific and socio-scientific contexts. The items of the questionnaire addressed the empirical, tentative, and subjective aspects of NOS. Quantitative and qualitative analyses were conducted to answer the research questions. Results showed that participants' views of the emphasised NOS aspects were mostly inconsistent. Plus, there was variance in participants' views of NOS between scientific and socio-scientific issues. Discussion of the results related to differential developmental progression, contextual factors, social constructivist perspective, different domains of knowledge, and students' individual differences.

ARTICLE HISTORY
Received 1 February 2016
Accepted 24 January 2017

KEYWORDS
Nature of science; scientific literacy; high school

Introduction

The question about how people learn science and how they apply the knowledge in their everyday lives is never outdated or unfashionable. In particular, the issue about how learners apply their conceptions to a concept area is important to understand. In this research study, we address this issue in relation to consistently applying the conceptions of nature of science (NOS) within different contexts. In this paper, context refers to a specific situation with a specific setting. And consistency needs to be viewed as any one person approaching tasks in a similar manner across topics or contexts.

Why does understanding the consistency of students' views matter? It is important for students to use scientific ideas steadily in alternative settings. Students' reasoning process needs to take place in a well-defined, consistent and logical context. The use of views consistently across different tasks shows that scientific knowledge is coherent and well defined. Some studies on students' views showed coherent and consistent knowledge,

CONTACT Rola Khishfe rk19@aub.edu.lb Department of Education, American University of Beirut, P.O. Box 11-0236, Beirut, Lebanon

while others revealed a fragmented and unconnected nature of knowledge. Some researchers argue that students seem to have a capability to work with coherent explanations in multiple representations consistent with the way scientific ideas are generated, and consequently generalise and transfer these ideas to a range of everyday situations. For example, students find difficulty in relating and transferring the scientific views into their daily experiences and their knowledge becomes fragmented. It is therefore important to explore whether the students develop well-structured and coherent structure of the theories or they make explanations that are fragmented, inconsistent and unconnected.

There is agreement that the naïve conceptions of learners are different from the conceptions of scientists in content and organisation (BouJaoude, 1991; Nakhleh, 1994). However, there is a debate about the qualitative nature of novice learners' ideas. Researchers have addressed this issue from different perspectives: knowledge-as-theory and knowledge-as-pieces. The knowledge-as-theory perspective considers that students have coherent and consistent naïve theory-like frameworks or views about the natural world (e.g. Carey, 1985; Ioannides & Vosniadou, 2002; McCloskey, 1983). Chi, Slotta, and de Leeuw (1994) claim that novice learners' conceptions are theory-like and they are organised into different and mutually exclusive ontological categories called trees. These frameworks allow students to make consistent predictions across different domains. Generally, the perspective about the consistency of students' conceptions in science has been challenged by some authors, as di Sessa (1993, 1994) who considered the conceptions as 'knowledge in pieces' that are fragmented, diffuse, independent, isolated, and context-dependent. He referred to these representations as phenomenological primitives, or p-prims. The consistency of these representations would be lost from person to person and from context to context (di Sessa, 1996). BouJaoude (1991) found students' ideas about burning to be fragmented, inconsistent, task-specific, and context-bound. These intuitive ideas or views would be inconsistent across different contexts (Caravita & Hallden, 1994; Clough & Driver, 1986; Cooke & Bredin, 1994; Palmer, 1993).

Even so, there is another perspective among researchers (Nakhleh, 2001; Taber, 2000) about the nature of learners' ideas, suggesting that learners can hold several alternative stable and coherent explanatory schemes, which are applied across a range of contexts. Nakhleh (2001) argued that students' conceptions are a mixture of theory-like and p-prim-like explanations. She visualises knowledge acquisition in chemistry as a spectrum with students' conceptions ranging from p-prims to fully developed theories.

With the divergent positions about the consistency in views, there are several empirical studies that compared views of the same person across different contexts or tasks. These contexts can address scientific or socio-scientific issues. A socio-scientific issue refers to a science-related social open-ended problem (Sadler & Zeidler, 2005) that is open-ended, ill-structured, and involves multiple perspectives and interpretations (Kolsto, 2001a; Sadler & Zeidler, 2005). This knowledge about the consistency in students' views is important for curriculum design and classroom practice. Below, we discuss empirical studies that address the consistency in views of science concepts.

Consistency in views of science concepts

On the one hand, many studies found in the literature investigate the consistency of science ideas of high school students by incorporating questionnaires that ask them to explain science phenomena and ideas. Similarly, the current study investigated high school students' NOS views by asking them to explain scientific and socio-scientific issues via a questionnaire. The studies discussed below target science ideas and are grouped according to their results as follows: studies with inconsistent views, studies with consistent views, and studies with mixed views.

Studies with inconsistent views

Clough and Driver (1986) explored students' ideas or conceptual frameworks in areas of physical and biological sciences and investigated the consistency with which students used the ideas in different contexts. Eighty-four students between the ages of 12 and 16 were asked to explain different phenomena in the form of several tasks relating to areas such as pressure, heat transfer, and different phenomena relating to the acquisition of biological characteristics. The study showed that only some individuals used accepted or informed ideas consistently across contexts. However, the scientifically incorrect ideas were rarely used consistently by students. So, students used different alternative frameworks in response to parallel questions. The results caused the authors to doubt the assumption that students, like scientists, have systematic conceptual frameworks. It is also noteworthy to highlight the finding that accepted or informed ideas were used more consistently by students than were alternative ideas. The authors suggested that once students learn and use a correct scientific explanation in one context, then they are more likely to use it in other contexts. In relation to the topic about linear motion, Palmer (1993) investigated the degree of consistency of the responses of Year 10 students using an instrument that consisted of eight multiple-choice questions. The results indicated that most students were unable to consistently apply the alternative conceptions or the scientific responses. Contrary to the current study, which focused on high school students, other studies investigated the consistency of science views across a wide range of grade levels. Bar and Galili (1994) focused on primary students' ideas regarding evaporation. Their results were consistent with that of Osborne and Cosgrove (1983), in that students' ideas vary throughout various scientific domains and topics and it is difficult to change or replace their ideas. Fassoulopoulos, Kariotoglou, and Koumaras (2003) have focused on the study of density and pressure. A significant number of students have shown inconsistent views. In a previous study, Tytler (1994) explored the consistency of primary school children's explanations of air pressure. Children wrote explanations for six tasks they had experienced in groups. Results showed that children's explanations were not consistently applied across contexts. Rather, children were applying multiple explanations even within the same task. Smothers and Goldston (2010) have also investigated the consistency of explanations of two seventh- and ninth-grade blind students within a certain theoretical framework. Their views were examined in the context of four tasks related to changes in matter. Results showed that the two students used views inconsistently across the different activities.

Studies with consistent views

Other studies explore the consistency of science views associated with younger students. Tytler (2000) has compared year 1 and year 6 students' consistency regarding evaporation and condensation using group discussions, written responses, and interviews. Both groups of students revealed consistency in their display of ideas. Samarapungavan and Wiers

(1997) also examined whether children's conceptual systems demonstrated properties of explanatory coherence. They reported that elementary students showed consistent explanatory frameworks about the origin of biological species. The authors referred to these explanations as explanatory frameworks, which they defined as internally consistent conceptual systems that embed individually consistent concepts that are mutually consistent with other concepts in the framework. Other studies explored the consistency with older students. For instance, a three-year longitudinal study conducted by Johnson (1998a, 1998b) examined students' understanding of the boiling of water. The participants were 147 students at the secondary level of age 11–14. The author found that there is consistency and coherence in the students' responses, where they rely on their existing knowledge to make sense of the boiling and condensing phases. Along the same lines, Kwen (1996) found that secondary students applied frameworks (whether informed or naive) consistently across groups of events targeting chemical reactions that students perceived to be similar. Pozo and Gomez-Crespo (2005) explored the consistency of views about the nature of matter held by students of varying levels of instruction from ages 12 to those with advanced studies in chemistry. Similar to the current study that required students to explain scientific and socio-scientific topics via a questionnaire, participants responded to two questionnaires that comprised 12 everyday situations. Results showed a consistent use of intuitive representations across the different situations.

Studies with mixed results

More recently, Kirbulut and Beeth (2013) addressed students' consistency of ideas across multiple related concepts; evaporation, condensation, and boiling. They conducted case studies with two participants. Their study revealed that the two students had different degrees of consistency and inconsistency in their ideas and that they also did not use different scientifically accepted ideas consistently across questions about evaporation, condensation, and boiling.

With the different positions related to the consistency of views in science and the empirical studies associated with that, an important question to ask would be related to the consistency of NOS views. It is important to understand the conceptions of NOS within and across contexts or disciplines.

Nature of science

Helping students to understand NOS is critical for achieving scientific literacy, which is addressed in the different reform documents in science education (e.g. American Association for the Advancement of science [AAAS], 1989, 1993; Council of Ministers of Education Canada [CMEC] Pan-Canadian Science Project, 1997; Curriculum Council [Western Australia], 1998; Millar & Osborne, 1998; National Research Council [NRC], 1996). NOS refers to the beliefs inherent in the development in scientific knowledge (Lederman, 1992). Even with no agreement among philosophers of science, historians of science, and science educators on a specific definition for NOS, there is an acceptable level of generality about some characteristics of the scientific enterprise (Lederman, 2007) that are accessible and relevant to K-12 students' everyday lives (Abd-El-Khalick, Bell, & Lederman, 1998). These aspects include understanding that scientific knowledge is tentative (subject to change in light of new evidence or reconceptualisation of prior evidence);

empirically based (based on and/or derived from observations of the natural world); subjective (influenced by prior knowledge, as well as theoretical and personal frameworks of the scientist); partly the product of human imagination and creativity (involves invention of explanations); socially and culturally embedded (both influences and is influenced by the cultural milieu); and utilises both observation and inference. An additional aspect is the relationship between scientific theories and laws (Abd-El-Khalick et al., 1998).

Consistency in views of NOS

The issue about the consistency of NOS views among various contexts has not been pursued at length in the science education research. There were only few studies that have indirectly explored this issue in relation to NOS views. Below is a discussion of these studies, which are grouped according to their results as follows: studies with consistent views, studies with inconsistent views, and studies with mixed views.

Studies with inconsistent views

Leach, Millar, Ryder, and Séré (2000) investigated the consistency of the students' epistemological reasoning within different contexts. Three forms of epistemological reasoning were found; data-focused reasoning, radical relativist, and knowledge- and data-related reasoning. Little consistency was observed. In another study, Khishfe (2008) found that students held inconsistent views of the same NOS aspects when responding to different questionnaire items representing different contexts. In that study, the inconsistent views were referred to as transitional. However, the issue of consistency of NOS views was not a main focus of that study and the NOS questionnaire used was not geared to measure learners' conceptions of the same NOS aspects across different contexts.

Studies with consistent views

Topcu, Sadler, and Yilmaz-Tuzun (2010) did not address the NOS, but they investigated the consistency of informal reasoning of 39 Turkish preservice science teachers within different socio-scientific issues. Participants responded to three scenarios addressing gene therapy, three scenarios about human cloning, and one scenario about global warming. The informal reasoning was significantly consistent within related scenarios dealing with gene therapy, but they were not significant among the cloning ones.

Studies with mixed results

In her study, McDonald (2010) referred to the consistency of NOS in both scientific and socio-scientific contexts even though that was not among the purposes of the study, which aimed to investigate the influence of a science content course including explicit NOS and argumentation instruction on five preservice teachers' views of NOS. In that study, NOS views were compared across different assessments: the Views of Nature of Science Questionnaire 'VNOS-C' (Abd-El-Khalick, 1998), the superconductors survey, and the global warming task. The VNOS-C was represented as addressing scientific contexts and was given as pre- and post-instruction. The superconductors survey also corresponded to a scientific context and was given as pre/post. The global warming task was characterised as a socio-scientific context and was given only as post-instruction. Results showed that participants' views of NOS (the empirical, subjective, and theory-laden), as assessed by the pre-instruction VNOS-C, were closely aligned with participants' views of these NOS aspects expressed in the pre-instruction superconductors survey. At the conclusion of the study, the post-instruction views of these examined NOS aspects for two of the participants were partially informed and/or informed and were aligned between the VNOS-C and the superconductors survey. For another participant, the expressed views of the examined NOS aspects were limited and that was consistent across both instruments. However, that was not the case for the two remaining participants as their post-instruction views of the examined NOS aspects were not aligned between the two instruments. The author also found that participants' views of NOS aspects were consistent between socio-scientific context (global warming task) and the VNOS-C. Furthermore, the author believed that it was not necessarily the case in scientific contexts, as some participants held views of NOS aspects that were not aligned between the scientific context and the VNOS-C. The author suggested the presence of multiple epistemologies as a possible explanation for these findings. However, these results need to be viewed with caution for several reasons. First, as the author herself noted, the empirical and subjective aspects found across both instruments (VNOS-C and the superconductors survey) were analysed using different coding schemes specific to the instrument, which limits the comparison of these NOS views. Second, there were only post-instruction data available for the global warming task that represented the socio-scientific context. Thus, there was no baseline for participants' views of NOS within that socio-scientific context. Third, the sample included only five participants. As such, there is a need to explore this issue with a bigger sample that represents students.

In addition, NOS has been addressed in the literature in either scientific or socio-scientific contexts. It is, therefore, important to examine NOS views in scientific and socio-scientific contexts. The differences between scientific and socio-scientific issues have been expressed by Latour (1987) as 'ready-made science' versus 'science-in-the-making.''Ready-made science' refers to the final product. This kind of science is characterised by a stable consensus among scientists that is not subject to challenge (Bingle & Gaskell, 1994). Knowledge claims considered as 'ready-made science' are seen as non-controversial statements about reality, as scientific facts (Kolsto, 2001a). This describes textbook science, which addresses the science content in schools, while 'science-in-the-making' is the science currently worked on in research. This science makes debatable claims with multiple interpretations by the scientific community and is subject to revision. Disagreements in this kind of science are as seen as natural and legitimate. This describes the science that is presented and debated at conferences, in journals, and among researchers. The lack of consensus among scientists concerning factual aspects is the reason why this continues to be an issue. For that reason, socio-scientific issues have been promoted as a natural and inherent context to discuss NOS ideas (Khishfe & Lederman, 2006; Matkins & Bell, 2007), as their discussion within that context can reveal to students the characteristics that compromise scientific knowledge.

The results from the literature are inconclusive in relation to the consistency in students' views of science. In general, previous studies have shown directly or indirectly that students hold inconsistent views of NOS in different contexts. Yet, none of these research studies clearly described how, if any, learners' views of NOS differ in different scientific and socio-scientific contexts. An in-depth study of this phenomenon at that level is needed. Therefore, a study that directly addresses this problem in relation to students' views about NOS is considered necessary. As such, the purpose of the study is to investigate the NOS views of students in different scientific and socio-scientific contexts. Thus, the questions that guided the present research were:

(1) Do students have consistent views of NOS aspects across different scientific and socio-scientific contexts?
(2) How do the students' views of NOS aspects differ across the scientific and socio-scientific contexts?

Method

Participants and context of the study

Participants in the present study were 261 high school students from eight schools located in Beirut, the capital of Lebanon. The schools were selected based on different geographical areas in Beirut and the principals' consent to participate in the study. The schools represented a variety of student socio-economic status and academic achievement. It is important to note that all selected schools were private medium-sized schools.

The student participants were a total of 261 grade 11 students, 137 females, and 124 males. The average age of students was 16 years. Twenty-seven students participated from school 1, 26 students from school 2, 38 students from school 3, 28 students from school 4, 28 students from school 5, 41 students from school 6, 34 students from school 7, and 39 students from school 8.

It needs to be noted that students have not received any instruction on NOS. The Lebanese curriculum neglects science as a way of knowing. NOS appears clearly in the general objectives of science education, but it is not emphasised in the more detailed curriculum (BouJaoude, 2002).

Only three NOS aspects (empirical, tentative, and subjective) were addressed in the present study. Author addressed these aspects in previous studies with the belief that these three NOS aspects are directly connected with the discussions about socio-scientific issues (Khishfe, 2012b; Zeidler, Walker, Ackett, & Simmons, 2002) so that it would ease the comparisons between scientific and socio-scientific issues.

Data collection and instruments

The study used a qualitative design to compare the responses of students across the different contexts. A five-item open-ended questionnaire, Nature of Science across Contexts (NOSC) (Appendix), was used to assess participants' NOS views. The questionnaire was followed by individual semi-structured interviews.

Questionnaire

The instrument was based on two items of VNOS C questions (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), which are the atomic structure and dinosaurs. The content validity of all the questions was further established by the input of experts (three science educators and five science teachers). The questions were modified based on the suggestions by these experts. For example, a sentence was added to the topic about plate tectonics to better explain the theory. Pilot study was also conducted with a group of grade 11 students prior to the study and a sample of students was interviewed. Based on that, some of the sentences were revised to address the readability level of students.

The NOSC questionnaire includes five topics that address scientific and socio-scientific issues (SSI). The first topic concentrates on the atom, a scientific issue. The second topic addresses dinosaurs, a scientific issue. The third topic deals with global warming, which is a socio-scientific issue. The fourth topic focuses on plate tectonics, a scientific issue. And the last topic tackles genetically modified food, a SSI. The topics were purposefully selected to address a variety of scientific and socio-scientific issues. That would assess students' understandings of NOS in a variety of contexts.

The topics are followed by questions relating to NOS (Appendix), where respondents are asked to present their views about the tentative, empirical, and subjective aspects of NOS in relation to each of the five topics addressed. All participants were administered the questionnaire.

Interviews

To further establish the face validity of the questionnaire, semi-structured individual interviews to a representative sample of students followed the administration of the questionnaires. During the interviews, participants were asked the same questions of the questionnaire and they were asked to further explain their responses. The interviews were used in order to insure that the researchers' interpretations corresponded to those of participants. A random sample of 20% of the total students was chosen for individual interviews. Lederman et al. (2002) found that interviewing 15–20% is adequate to determine the meaning associated with a certain group of participants in a certain context. All interviews were transcribed verbatim.

Data analysis

The interview transcripts and the corresponding questionnaires were analysed separately to generate profiles of participants' views of the target NOS aspects. The two profiles, which were independently generated, were compared for each interviewed participant. Then, each participant questionnaire was analysed to categorise students' responses, which were categorised into naïve, informed, or intermediary for each NOS aspect.

(1) point: naïve or no response
(2) points: intermediary
(3) points: informed

The author and another science education researcher categorised participants' understandings separately. At first, the two researchers met several times to discuss the framework and then analysed some of the cases together till consensus was reached. The two researchers then analysed the cases independently. The inter-coder reliability between the two researchers was 86%. Multiple consultations of the data were needed till consensus was reached between the two researchers.

A participant's view was categorised as naïve when he/she did not exhibit any informed view of the target NOS aspect. A 'naïve' view is not consistent with the contemporary views of NOS. A view was categorised as intermediary, and one form that might occur is the multiple (Khishfe, 2008). These are co-existing fragmented views, which sometimes contradict each other. An 'informed' view corresponds with contemporary views of NOS accepted by science philosophers, scientists, and science educators. Table 1 presents examples about the categorisation of responses to the question about atomic structure related to the three NOS aspects. Table 2 presents examples about the categorisation of responses to the question about plate tectonics related to the three NOS aspects.

To quantitatively answer the questions of interest, one-way multivariate analysis of variance (one-way MANOVA) in the *Statistical Package for the Social Sciences* (SPSS) was performed. First, the analyses were carried out for the five different contexts and students' views of the empirical, tentative, and subjective aspects of NOS. The MANOVA was followed by Tukey post-hoc test. Then the analyses were carried out for the two contexts (scientific and socio-scientific) and students' views of the empirical, tentative, and subjective aspects of NOS.

Qualitative analysis was also conducted to answer the research questions. The responses of each participant were compared across the different contexts (items). Then the percentages of participants who hold consistent views or inconsistent views across the different items were calculated. The criteria for consistency adopted in the present study was as follows: a view was considered consistent if the participant gave an informed view for at least two of the three topics related to the scientific contexts, and for the two topics related to the socio-scientific contexts.

Table 1. Categorisation of responses to the question about atomic structure related to the three NOS aspects.

NOS aspect	Naïve views	Intermediary views	Informed views
Subjective	Because of the different atomic structure	Scientists might not be using the same data or they determine this atomic structure by the bonds of the atom and number of protons, neutrons, and electrons … they are sure of the structure since they made many experiments	Scientists came up with different theories as they look at atom from different perspectives and were able to reach structure through a number of evidence
Tentative	Yes, scientists are sure of the atomic structure. Proof that the structure of the atom is certain comes from information from the periodic table and the electrons that are placed on the valence shells. All information seems to be correct and accurate according to the periodic table	They are sure about the structure because many experiments proved that but science develops every day and they might discover new molecules or find some difference in the structure	No, scientists are unsure about atomic structure because as the world develops and as scientists go deeper into finding new things, I think that as the future comes, previous predictions and conclusions would probably be changed by new evidence
Empirical	They are sure of the atomic structure because they see it under the microscope	… new evidence about the atom constantly forced the structure to change in order for it to be logical … they can also see it through the microscope	Scientists determined the atomic structure by projecting alfa beam to a gold rod which reflected some of its rays which mean there is a nucleus with protons and neutrons …

Table 2. Categorisation of responses to the question about plate tectonics related to the three NOS aspects.

NOS aspect	Naïve views	Intermediary views	Informed views
Subjective	Earth changes during time … first scientists think less realistic than today and so most of old theories are false.	Scientists come up with different and illogical theories concerning Earth. This is due to scientists not fully understanding the planet and its motion and structure. They could have different perspectives to look at things	Different ideas and different people lead to different conclusions. Different ways of analysing data. It is based on one's way of thinking
Tentative	Scientists are certain of the theory of plate tectonic because they can experience the movement	Yes, scientists are sure about the theory of plate tectonics or they wouldn't have told society … Nothing in science is sure	Scientists might not be sure. As research develops and develops, new ideas and theories change
Empirical	Scientists know about movement of plates because the ground cannot move on its own	Due to the study of under lands, scientists make hypothesis and finally gotten a conclusion. They have special tools and equipment for those things in order to see them	By geological studies, scientists dig through the Earth and analyse, study, and conclude. They take care of every single detail that will help them. In addition, they examine the plates and compare them and study their movements

Results

The results were looked at in the realm of participants' understandings of the three NOS aspects from two angles: (a) across the different contexts addressed in questionnaire, and (b) across scientific and socio-scientific contexts. Quantitative and qualitative analyses showed that students' views of the empirical, tentative, and subjective aspects were significantly dependent on the context. There were differences in the percentages of students' informed views for the three aspects of NOS across the different contexts (atom, dinosaur, plate tectonics, global warming, and genetically modified food). As for the other perspective, students' responses were significantly dependent on whether the context was scientific or socio-scientific. It was also noted, that quantitatively and qualitatively, there were more consistent views of the two NOS aspects (tentative and subjective) across the scientific issues, as compared with the socio-scientific ones.

Consistency of views within different contexts

For the quantitative analyses, the MANOVA that were carried out showed that students' views of the empirical, tentative, and subjective aspects were significantly dependent on the context. There was a statistically significant difference in students' views to the empirical, tentative, and subjective based on the context, $F(12, 3435) = 30.85$, $p < .0005$. To determine how students' views of the three NOS aspects differ by the independent variable (context), we looked at the Tests of Between-Subjects Effects. Results showed that the context of the item has a statistically significant effect on students' views of the empirical ($F(4, 1300) = 70.44$, $p < .0005$), students' views of the tentative ($F(4, 1300) = 18.26$, $p < .0005$), and students' views of the subjective ($F(4, 1300) = 5.39$, $p < .0005$).

The results were followed with Tukey's Honest Significant Difference (HSD) post-hoc tests and they showed that students' views of the empirical aspect were statistically significantly different between context 1 (atom) and context 2 (dinosaurs) ($p < .0005$), context 1 and context 3 (global warming) ($p < .0005$), context 1 and context 4 (plate tectonics) ($p < .0005$), and context 1 and context 5 (genetically modified food) ($p < .0005$). Results also showed that students' views of the tentative aspect were not statistically significantly different between context 1 and context 2 ($p = .999$), but statistically significant between context 1 and context 3 ($p < .0005$), context 1 and context 4 ($p < .0005$), and context 1 and context 5 ($p < .0005$). As for the subjective aspect, results showed that students views of that aspect were not statistically significantly different between context 1 and context 2 ($p = .335$), context 1 and context 3 ($p = .995$), context 1 and context 4 ($p = 1.00$), as well as context 1 and context 5 ($p = .054$).

At the qualitative level, we closely examined the individual questionnaires and the interviews to look for possible trends. Following is a discussion of these results.

Empirical aspect of NOS

Starting with the empirical aspect, the highest percentages of participants with informed views were found with the dinosaur and global warming contexts. Table 3 presents an overview of these percentages in the different contexts. A great majority of participants (90%) had informed views in response to the dinosaurs question. For example, one of the participants stated that 'scientists believe that dinosaurs existed, since some of their bodies that were buried underground such as their bones, were found by scientists that gave some evidence that dinosaurs do exist.' At the same time, a great majority of participants (95%) exhibited informed views when responding to the question about global warming. For example, the following two participants related to the evidence about the rise in temperature:

> The global warming is happening. Okay, how do scientists know that? Well, they know because of rise of temperature, they know because of the worldwide increase of heat level … we have many indications about global warming that it is happening (S210, global warming, interview)

> Scientists are almost certain about global warming (no scientist is ever completely certain about anything). They are almost certain because they have live examples of the effects that they believe are caused by global warming as temperature rise (S140, global warming, questionnaire)

This percentage of participants with informed views decreased with the other contexts. Only 23% of participants had informed views in response to the atom question. For example, this participant explained that 'scientists determined the atomic structure by experimenting and trying in the lab, until they reached the above atomic structure, and

Table 3. Percentage of participants with naïve, intermediary, and informed views of empirical aspect of NOS across the different contexts.

	Naive	Intermediary	Informed
Atom	68% (177)	11% (30)	21% (54)
Dinosaurs	7% (19)	14% (37)	79% (205)
Plate tectonics	37% (96)	22% (58)	41% (107)
Global warming	17% (45)	15% (38)	68% (178)
Genetic engineering	49% (128)	8% (21)	43% (112)

due to data obtained.' Another participant related to Rutherford experiment; she explained that scientists determine the given atomic structure 'by conducting several experiment sending rays on gold sheets and seeing if they reflect or attract.' Other participants mentioned the scientist Rutherford by name:

> Rutherford did an experiment where he put a piece of gold and he put alpha rays some of these rays deviated from their original path and so he concluded that there is a nucleus containing protons and electrons flow around it. (S107, atom, questionnaire)

There were also some participants who held intermediary views about this aspect. For example, the following participant related to the experiments done to determine the atomic structure but then he mentioned that scientists had seen the atom by microscope:

> Scientists determined the atomic structure by evidence through the experiments they did. And of course they have seen the atom by microscope or else how do they draw it. (S4, atom, questionnaire)

As for the context about plate tectonics, 47% of participants exhibited informed views about the empirical aspect. For example, the following participant explained that 'if you put them [continents] back together they would fit perfectly so that shows their conclusion about plate tectonics.' With regard to the context of genetic engineering, 48% of participants elucidated informed views about the empirical aspect. For example, one participant related to 'the studies they do to know how eating genetically modified food might affect us and how does it affect us in different ways.'

Consistency for informed views of the empirical aspect was also prevalent among the participants. Following is an example of one participant (S52) who showed consistency in relating to the role of evidence in the work of scientists to reach their conclusions when responding to all different contexts:

> The scientists determined the atomic structure after many studies and experiments that they have tried and documented until they come up with this structure. (S52, atom, questionnaire)

> The scientist know that dinosaurs really exist because of the presence of their bones which can help them to determine and come up with the structure of the body of dinosaurs. (S52, dinosaurs, questionnaire)

> The scientists know that the global warming is happening because the ice that is present at the north and South Pole are melting along with other evidence and that is why they came up with that. (S52, global warming, questionnaire)

> The scientists knew about the constant movement of plates after realizing that by time 'around thousand years' the formation of the land has changed so that how they reached conclusion. (S52, plate tectonics, questionnaire)

> The scientists know about its effects of genetic engineering after they experimented it with several studies to study what happened with genetic engineering so that way they studied its effects. (S52, genetic engineering, questionnaire)

To sum up, more than half of the participants (52%) showed inconsistent views of the empirical aspect for the scientific contexts, as compared to 64% for the socio-scientific contexts (Table 4). However, 47% of participants showed consistent views of this aspect for the scientific contexts, as compared with 36% for the socio-scientific contexts.

Table 4. Percentage of participants with consistent and inconsistent views of empirical, tentative, and subjective aspect of NOS across the scientific and socio-scientific contexts.

	Empirical	Tentative	Subjective
Consistent			
Scientific	47% (123)	8% (20)	15% (40)
Socio-scientific	36% (93)	1% (3)	9% (24)
Inconsistent			
Scientific	53% (137)	92% (239)	85% (221)
Socio-scientific	64% (168)	99% (258)	91% (237)

Tentative aspect of NOS

As for the tentative aspect, Table 5 presents an overview of these percentages in the different contexts. A large majority of participants (84%) had no informed views within the atom context with the majority providing naïve answers about whether scientists are certain about the atomic structure. One of the participants (S97) believed that 'scientists are fairly sure about the structure since it isn't a theory and this structure has been viewed by the human eye using special devices.' Some have stated that the presence of 'microscopes allow us to see on molecular and atomic levels,' and 'new technologies can help determine and see microscopic details.' Others declared that 'scientists are sure about the structure of the atom since they made many experiments and they depended on this structure 100's of years.'

A majority of participants (77%) exhibited naïve and intermediary views as they addressed the dinosaurs topic. For example, this participant believed that scientists are certain about the structure of the dinosaur because they have written about them and also drawn them:

> Yes they are sure because in history they used to draw and write about dinosaurs so of course they are sure. (S79, dinosaurs, questionnaire)

Similarly, a great majority of participants held naïve and intermediary views in relation to both contexts of global warming and genetic engineering topics with 95% and 92% of participants, respectively. Examples of their naïve responses towards the global warming phenomena included 'the fact that climate is changing so the knowledge about global warming will change,' and 'global warming had had a huge impact on the earth's atmosphere causing many earth residents to feel the change in temperature so our knowledge will change.' For the genetic engineering, the participants' attention shifted to experiments as a way to reach absolute knowledge where one participant explained in his interview that

> experiments were done to find out the effects of genetic engineering because before someone wants to finally close his research, it must be tested and verified. When it is verified more than once, then it's definitely proved to be effective or not. So it is absolutely 100% certain.

Table 5. Percentage of participants with naïve, intermediary, and informed views of tentative aspect of NOS across the different contexts.

	Naive	Intermediary	Informed
Atom	72% (188)	14% (37)	14% (36)
Dinosaurs	67% (175)	14% (35)	19% (50)
Plate tectonics	87% (226)	7% (19)	6% (16)
Global warming	87% (228)	9% (22)	4% (10)
Genetic engineering	87% (227)	7% (18)	6% (16)

Similarly, the percentage of participants with naïve and intermediary views was high (93%) when responding to the plate tectonics question. Following are example of students' responses:

> Scientist CAN'T officially state a fact without them being certain (sure) so my answer is that scientists stated them so they are certain. (S81, plate tectonics, questionnaire)

> Plate tectonics, it is just a theory that needs to be proven. (S86, plate tectonics, questionnaire)

One trend that was noticed in relation to the participants' views of tentative aspect was the consistency in their naïve views. These participants considered that everything in science needs to be 'absolute,' 'proven', and '100% sure' or else, as shown in the following quotations:

> Yes, proof that the structure of the atom is certain comes from information in the periodic table, and the electrons that are placed on the valence shells. All the information seems to be correct and accurate according to the periodic table … it is proven. (S215, atom, interview)

> Yes. The fossils found and collected by scientists have been put back together, determining the exact skeleton of a specific dinosaur. I am sure about this because of the life-size skeleton fossils what are in museums. (S215, dinosaurs, questionnaire)

> I think they are sure about plate tectonics since they didn't change and because they are teaching us about it. (S134, plate tectonics, questionnaire)

> Yes, the knowledge about genetically modified food has already been proven. (S12, genetic engineering, questionnaire)

> I think they are sure because they depended on this 100's of years (S135, global warming, questionnaire)

Only a minority of participants (ranging from 5% to 23%) elucidated informed views of this aspect, where they related the change in scientific knowledge to evidence or reinterpretation of data:

> Scientists are somehow sure about this structure yet due to the evolution of technology and life it might change or they might get to see it differently. (S118, atom, questionnaire)

> Scientists, in my opinion, are uncertain about what exactly causes global warming. There is partial evidence exists, but these maybe other factors that contribute to the more than a 'hole in the ozone layer'. Factors that we are unaware of yet, whether natural or not … could be new evidence. (S97, global warming, interview)

Consequently, only one participant showed consistency in his informed views about the tentative aspect of NOS, where he believed that scientific knowledge is not absolute and '100% true' when responding to the different questions:

> No scientists are not sure about atomic structure because in science nothing is 100% sure, they perform experiments and get results. (S78, atom, questionnaire)

> No but they have a general idea because they are finding fossils recently and the researches are in progress. With each new bone, they will formulate a new idea so not 100% sure. (S78, dinosaur, questionnaire)

> Yes because we are starting to feel global warming right now in our time. We have the data for it but there is nothing 100% sure in science. (S78, global warming, questionnaire)

> Yes because of the evidence which support this but again there is nothing 100% sure in science. For example, we might wake up tomorrow and there is a new study. (S78, plate tectonics, questionnaire)

> No because nothing is 100% sure in science so we might have a new study about genetic engineering. (S78, genetic engineering, questionnaire)

In summary, the greater majority of the participants (92% and 99%) showed inconsistent views of the tentative aspect for the scientific contexts and the socio-scientific contexts, respectively (Table 4). However, a minority of participants (8% and 1%) showed consistent views of this aspect for the scientific and socio-scientific contexts.

Subjective aspect of NOS

Regarding the subjective aspect, most participants did not exhibit informed views. Table 6 presents an overview of these results in the different contexts. A large majority of participants (between 77% and 80%) elucidated naïve and intermediary views when responding to the questions about the atom, plate tectonics, genetic engineering, the dinosaurs, and global warming topics.

A common view that was consistently noted in response to the different contexts by some participants is the focus on time as a way to explain how scientists reach different conclusions when looking at the same data. These participants did not always understand that scientists build on the work of other scientists. For the atom, one participant mentioned that 'scientists came up with different models since the materials and objects they use are different at different times. And by the time pass, they will have more chance to find the right structure and the right answer.' For the context of dinosaurs, one participant explicated the difference in scientists' conclusions by having not only different evidence but that evidence is found at different times too:

> The cause of scientists coming to different conclusions is due to different evidence, at different timings. (S45, dinosaurs, questionnaire)

When responding to the question about plate tectonics, one participant stated that 'scientists can reach different conclusions because each scientist works at a different time than the other scientists so knowledge will be different.' As for the context of global warming, one participant explained that

Table 6. Percentage of participants with naïve, intermediary, and informed views of subjective aspect of NOS across the different contexts.

	Naive	Intermediary	Informed
Atom	72% (187)	13% (34)	15% (40)
Dinosaurs	61% (159)	18% (47)	21% (55)
Plate tectonics	72% (188)	11% (29)	17% (45)
Global warming	67% (172)	13% (34)	20% (52)
Genetic engineering	74% (195)	8% (20)	17% (44)

it's possible to come up with different conclusions upon working with the same data and it's because they're a lot of factors causing it and they're not really sure about it. Plus because some scientists work in different times.

When responding to the question about genetic engineering, many participants related the differences to differences in methods and equipment:

[Scientists can reach different conclusions when looking at same data] probably because of different methods of experimentation and observations at different time or might even be because of different kinds of experimental equipment which they use. (S33, plate tectonics, questionnaire)

Another trend related to the consistency in participants' naïve views of the subjective aspect was also noted. These participants explained that scientists can have different conclusions since they have different evidence or data:

Scientists might be looking at different experiments so thus reach different conclusions. (S117, atom, questionnaire)

This can happen by studies and researchers for dinosaurs. If the 2 groups suggested different theories, they must be using different evidence and clues. (S117, dinosaurs, questionnaire)

Scientists came up with different conclusions because they look at different clues. (S117, plate tectonics, questionnaire)

Scientists came up with different and sometimes illogical theories concerning Earth. This is due to a scientist not fully understanding the planet and its motion and structure and looking at different evidence but as we progress and learn more about Earth's reality, we can prove or disprove theories related to these natural phenomena. (S117, global warming, questionnaire)

Scientists reach different conclusions since genetically modified food is something unfamiliar to humans. These scientists predict what the positive effects can be such as quality of the food, but at the same time, they look at different studies so they get different conclusions in the long run. (S117, genetic engineering, questionnaire)

Only few participants showed informed views about the subjective aspect of NOS consistently across the different contexts. These participants explained that scientists interpret the data differently based on their beliefs and biases, as was the case with this participant:

Scientists came up with different models because everyone was looking at the atom in their own way. Every scientist continues what the previous one started. (S59, atom, questionnaire)

Every scientist interprets the data differently because he is different thus coming up with different conclusions. (S59, dinosaurs, questionnaire)

Every scientist has his or her studies and researches thus those researchers might differ because every scientist might study part of the data and not all and that affects the conclusion. (S59, plate tectonics, questionnaire)

The different theories come up according the scientist's beliefs and every scientist has his beliefs thus several theories will be said about that matter. (S59, global warming, questionnaire)

Some scientists might ignore certain facts and concentrate on others and this leads to different conclusions for the same topic. (S59, genetic engineering, questionnaire)

To sum up, a greater majority of the participants (85% and 91%) showed inconsistent views of the subjective aspect for the scientific and the socio-scientific contexts (Table 4), while a minority of participants (15% and 9%) showed consistent views of this aspect for the scientific contexts and the socio-scientific contexts.

Consistency of views across scientific versus socio-scientific contexts

Quantitatively, the MANOVA that were carried out showed that students' responses were significantly dependent on whether context was scientific or socio-scientific. There was a statistically significant difference in students' views to the empirical, tentative, and subjective aspects based on whether the context is scientific or socio-scientific, $F(3, 1301) = 21.95$, $p < .0005$. Results also showed that for the tentative and subjective aspects, students did better in the scientific context. For the tentative aspect, the means were 1.54 and 1.28 for the scientific and socio-scientific, respectively. As for the subjective aspect, the means were 1.8 and 1.62 for the scientific and socio-scientific, respectively. Next, we looked at the Tests of Between-Subjects Effects. Results showed that the context of the question (whether scientific or socio-scientific) has a statistically significant effect on students' views of the empirical ($F(1, 1303) = 8.09$, $p = .005$), students' views of the tentative ($F(1, 1303) = 42.28$, $p < .0005$), and students' views of the subjective ($F(1, 1303) = 11.96$, $p = .001$).

At the qualitative level, we closely examined the individual questionnaires and the interviews to look for possible trends. The consistency of students' views of NOS was looked at in relation to the three emphasised NOS aspects. Tables 7–9 give an overview about the percentage of participants with informed views of the three emphasised NOS aspects across the scientific and socio-scientific contexts. Following is a discussion of these results.

Empirical aspect of NOS

For the empirical aspect of NOS, only a minority of participants (7%) did not show any informed views in relation to the scientific contexts, compared with 15% of participants with no informed views in relation to the socioscientific issue (SSI) context. An almost equal percentage of participants (39% and 41%) exhibited one and two informed views for the scientific and socio-scientific contexts. None of the participants exhibited three informed views of the empirical aspect when responding to the SSI contexts. This is in contrast to the scientific context, where 13% held three informed views when responding to the scientific contexts.

One of the trends that showed consistency in scientific and socio-scientific contexts was the notion of 'seeing is believing' that was prevalent in the responses of participants and

Table 7. Percentage of participants with informed views of empirical aspect of NOS across scientific and socio-scientific contexts.

	Participants with no informed view	Participants with one informed view	Participants with two informed views	Participants with three informed views
Scientific issues	16% (42)	36% (95)	36% (94)	11% (29)
Socio-scientific issues	25% (66)	39% (102)	36% (93)	

Table 8. Percentage of participants with informed views of tentative aspect of NOS across scientific and socio-scientific contexts.

	Participants with no informed view	Participants with one informed view	Participants with two informed views	Participants with three informed views
Scientific issues	71% (184)	21% (55)	6% (15)	2% (5)
Socio-scientific issues	92% (239)	7% (19)	1% (3)	

which indicated a naïve view of the empirical aspect. For example, the following participant was consistent in scientific (atom) and socio-scientific (global warming) contexts in relating the belief to actually 'seeing' the phenomenon:

> I don't think they are sure of the atom's structure because we can't see it in the naked eye nor on microscope … we cannot see it so how can we know. (S162, atom, interview)

> I don't think they are sure because they can't see the ozone layer & how it is affected. (S162, global warming)

The consistency in participants' views of the empirical aspect in scientific and socio-scientific contexts is also demonstrated in the following example with participant S52. This participant exhibited an informed view of the empirical aspect in all contexts. Starting with the scientific context, he stated that 'scientists determined the atomic structure after many studies with many failures until they reached this one as the best indication.' For the dinosaur question, he explained that scientists know that dinosaurs really exist 'because of the presence of their bones and other evidence that can hint to their form and habitat.' When responding to the question about plate tectonics, the participant explained that 'scientists knew about the constant movement of plates after realising that by time 'around thousand years' the formation of the land has changed so that makes us conclude about plate tectonics.' As for the SSI context about global warming, he explicated that scientists know that the global warming is happening 'because of the evidence of the ice that is present at the North and South Pole are melting.' And finally for the SSI context about genetic engineering, the participant stated that 'scientists know about its effects of genetic engineering after they have experimented about it many times and have done studies.'

A pattern consistent among the naïve views of participants and common to SSI contexts was participants' weariness of theories in not having enough 'proof.' These participants did not understand the value of evidence that scientists adhere to their conclusions, as shown in the following example:

Table 9. Percentage of participants with informed views of subjective aspect of NOS across scientific and socio-scientific contexts.

	Participants with no informed view	Participants with one informed view	Participants with two informed views	Participants with three informed views
Scientific issues	64% (167)	21% (54)	12% (32)	3% (8)
Socio-scientific issues	72% (188)	19% (49)	9% (24)	

> These are just based on theories they might not be true, theories do not have enough proof, it's what's their opinion is. (S18, genetic engineering, questionnaire)

> I believe that it's a theory and just like the big bang there are overloads of explanations. (S214, global warming, questionnaire)

Tentative aspect of NOS

As for the tentative aspect of NOS, the majority of participants did not hold informed views with 66% and 90%, respectively, within the scientific and SSI contexts. As such, many participants held naïve views about the tentative NOS across the five contexts. Participants seemed to hold more informed views about the empirical aspect compared with the tentative aspect of NOS. One quarter of participants (25%) exhibited one informed view in scientific context, compared to only 9% in SSI contexts. A minority of participants, 7% and 1% in scientific and SSI contexts, elucidated two informed views. And similar to the empirical aspect, a small minority of participants (2%) showed three informed views in scientific contexts compared to none in SSI contexts.

The consistency in participants' views of the empirical aspect in scientific and socio-scientific contexts is shown in the following example with participant S78. This participant S78 showed naïve views of the tentative aspect in response to questions targeting the scientific and SSI contexts. Starting with the scientific context, the participant (S22) explained that 'scientists determined the atomic structure but who can be sure of anything in science.' For the scientific context about dinosaurs, the participant acknowledged that 'scientists might determine a structure for the dinosaur but I do not believe they can find a strong clue so they cannot be sure of anything.' As for the plate tectonics, the participant asserted that 'scientists might find something about plate tectonics but they cannot know for sure about anything in science.' For the SSI contexts, the participant provided the same answer for both topics about global warming and genetic engineering by stressing on the notion that 'we cannot know about anything in science.'

As for the inconsistency between scientific and socio-scientific contexts, the following example captures the differences between the two contexts. For the scientific contexts, the participant indicated that scientists are certain about the scientific knowledge such as the atomic structure and plate tectonics because 'it is proven,' while scientists are not certain about the scientific knowledge in the context of SSI such as global warming and genetic engineering because they are dealing with 'just a theory that needs to be proven':

> In my opinion, scientists are sure about the structure of the atom nowadays since this is already proven. (S171, atom, questionnaire)

> I think they [scientists] are sure about the structure of the dinosaur since they have identified and proved their dinosaur structure. They have the structure in all of the movies. (S171, dinosaurs, questionnaire)

> I think they are uncertain due to the fact that climate is changing. Global warming had had a huge impact on the earth's atmosphere causing many earth residents to feel the change in temperature but it is just a theory. (S171, global warming, questionnaire)

> I think they are uncertain, it is just a theory that needs to be proven. (S171, plate tectonics, questionnaire)

> No, since they are just theories for genetic engineering that are not yet proven and acknowledged. (S171, genetic engineering, questionnaire)

Subjective aspect of NOS

Regarding the subjective aspect of NOS, a majority of participants (61% and 69%, respectively) did not hold any informed views in the scientific and socio-scientific contexts. Similar percentages of participants (22% and 21%) showed one informed view in scientific or socio-scientific contexts. A minority of participants (14%) elucidated two informed views in scientific contexts compared to 9% in socio-scientific contexts. Again, a small minority of participants (3%) exhibited three informed views in scientific contexts, as compared to none in the socio-scientific contexts.

The inconsistency in participants' views of the subjective aspect in scientific and socio-scientific contexts is shown with the following participant S141 who exhibited informed views of this aspect in socio-scientific contexts and naïve views in scientific contexts:

> Science is based on proofs and facts … When different scientist arrive at different theories then one of them made a mistake in his experiment. (S141, atom, interview)

> Scientists are changing, in early days up to now science keeps on changing and still is … Evidence changes so conclusions about dinosaurs keep changing. (S141, dinosaur, interview)

> Science is based on proofs, theories, and facts … Scientists reach the conclusion that is most correct and has proof and facts. (S141, plate tectonics, interview)

> Science is based on proofs, theories, and facts. All these three are based on the personal research of individual scientists. What a scientist believe is up to him, it's what he finds more convenient and logical. They arrive at different conclusions but this doesn't mean that one of them is wrong. (S141, global warming, questionnaire)

> What determines those theories about genetic engineering is the scientist himself. What determines those facts are the clues that scientist find and crack. What determines those clues is the trances, incidents, left behind for scientists to find later so scientists may reach different conclusions with genetic engineering. (S141, genetic engineering, questionnaire)

Another trend was captured in the consistency of participants' naïve views in the different targeted contexts. For example, one of the participants (S10) believed that'scientists should arrive at the same conclusion about the atomic structure.' She also explained that 'both groups of scientists should try everything together to reach one conclusion' in response to the context about dinosaurs. When asked about plate tectonics, this participant explained that 'scientists reach the same conclusion about plate tectonics.' This participant also responded that 'both groups should join their information together to get at one correct answer and know that it began natural then humans continued it' in response to the question about global warming. With respect to the question about genetic engineering, this participant stated that 'when scientists join their efforts, they can reach one conclusion about the effects of genetic engineering.'

Summary of results

When looking at participants' understandings of the three NOS aspects across the different contexts, quantitative and qualitative results showed differences in participants' informed views for the three aspects of NOS across the different targeted contexts (atom, dinosaur, plate tectonics, global warming, and genetically modified food). On close inspection, qualitative results showed that participants showed the highest percentage of informed views among participants for the empirical aspect of NOS (Table 3). In contrast, the tentative aspect showed the least percentage of informed views among participants, and that was consistent across the different contexts (Table 5). Moreover, there was more congruence in the informed views of the subjective aspect across the different contexts (Table 6). Regarding the second focus, quantitative and qualitative results showed that the consistency of participants' views of the two-targeted NOS aspects (tentative and subjective) was more prevalent in relation to the scientific issues, as compared with the socio-scientific ones.

Discussion

Helping students to understand NOS is a goal in science education (AAAS, 1989, 1993; NRC, 1996). The desired outcome is to have students understand the NOS aspects in different contexts. However, that has been difficult to achieve for students. Students usually learn a concept within a discipline, yet fail to understand the same concept when they face it in another discipline or even in another context in the same discipline.

For the first research question addressing the consistency of views across different contexts, quantitative results showed statistically significant difference in students' views of the three emphasised NOS aspects depending on the context. Similarly, qualitative results showed differences in the percentage of students having informed views for the three aspects: empirical, tentative and subjective across the different contexts. Students elicited consistency in having more informed views of the empirical aspect of the dinosaur and global warming issues, while students' views of the three aspects were mostly inconsistent across the different contexts (Table 4). These results support previous findings about inconsistency of informed views (e.g. Kirbulut & Beeth, 2013; Palmer, 1993), where students were unable to consistently apply the scientific responses in different contexts.

While investigating students' views of NOS aspects across different scientific and socio-scientific contexts addressed in the second research question, quantitative results showed statistically significant difference in students' views of the three emphasised NOS aspects whether the context is scientific or socio-scientific. Similarly, qualitative results showed differences in the percentage of students' informed views for the three aspects: empirical, tentative and subjective across the two contexts. These results revolve around the inconsistency of students' informed views with the socio-scientific issues in comparison with scientific issues. Each of the aforementioned issues belongs to distinctive scientific contexts, yet learners showed better responsiveness with the scientific issues versus the socio-scientific issues. Students were somewhat naïve when it came to more controversial issues, which is a core trait of socio-scientific content, demonstrating that it is more challenging for them to construct solid answers regarding this content of science. Consequently, these results support the finding by Clough and Driver (1986) who also studied students' consistency in different contexts. Their results showed the use of alternative frameworks, which made the authors doubt that students have systematic conceptual frameworks similar to scientists.

These results can be understood along five different interpretations: differential developmental progression, contextual factors, social constructivist perspective, different domains of knowledge, and students' individual differences.

Differential developmental progression

One explanation for the inconsistency in students' views of the emphasised NOS aspects can be taken to be an indicator of conceptual change (Watson, Prieto, & Dillon, 1997). In their study, Watson et al. (1997) examined 14–15-year-old students' responses to a questionnaire about combustion to explore whether students use alternative explanations consistently. Results showed that most students were consistent in applying their alternative frameworks but not the scientific frameworks. Many students were using both frameworks at the same time so the authors considered that they were in a transition phase towards the accepted scientific explanation (Prieto, Watson, & Dillon, 1992). This relates to a proposed evolving developmental model of progression in students' views of NOS (Khishfe, 2008). The variability of views across different contexts is referred to by Khishfe (2008) as transitional forms (a form of intermediary views or stages). In the present study, we further propose that the invariability of students' views in different contexts is due to a differential development of views within a progressive model.

Perry (1970) was among the first to discuss the idea of epistemological development in college students' thinking. His model included a sequence of nine hierarchically integrated positions ranging from absolutist 'dualistic' thinking to more 'relativistic.' Khishfe (2008) also proposed that the change in students' NOS views develop from naïve to intermediary to more informed. Several other models targeted epistemological development (Baxter Magolda, 1992; Belenky, Clinchy, Goldberger, & Tarule, 1986; King & Kitchener, 1994) and explained how the views of knowledge progress through developmental stages. This idea about the progression of epistemologies as in stages resonates with other Piagetian-type developmental schemes (Hofer & Pintrich, 1997). Along the same lines, other researchers (e.g. Linn & Songer, 1991; Metz, 1991; di Sessa, 1993) claimed that the development of students' views involves different stages, which are stimulated by 'effective' instruction. di Sessa (1993) proposed a framework that highlights p-prims and claims that the conceptual change occurs not by replacement of the p-prims, but by development and reorganisation of the whole structure.

Moreover, Watson et al. (1997) found that students used alternative frameworks inconsistently and he explained it to be the result of students' conceptual change. Yang (2005) investigated the 10th graders' personal epistemology and its impact over their views towards evidence and expert opinion within a socio-scientific topic. The study proposed that the 'the personal epistemology which has a developmental characteristic is a fundamental factor that influences the perceptions regarding the NOS of students at different developmental stages and further moulds their thinking and learning' (Yang, 2005, p. 67). In terms of the current study, it can therefore be argued that results showing inconsistent views of the three aspects of NOS across questions related to atoms, plate tectonics and genetic engineering are a product of early stages of conceptual change.

Contextual factors

Leach et al. (2000) justify the inconsistency of students' epistemological reasoning by stating that the context determines the epistemological knowledge the student needs to accomplish a task. Topcu et al. (2010) also found that informal reasoning about SSI depends on the context. According to Khishfe (2012a), the contextual factors could involve issue exposure and familiarity, as well as personal relevance. It was also noted by the authors that these contextual factors are interrelated and interact with each other.

Issue exposure and familiarity

In the present study, students showed more informed views in relation to the context about dinosaurs. It can thus be argued that these results are influenced by students' familiarity with the topic of dinosaurs and global warming (particularly for the empirical aspect of NOS). The topic of dinosaurs and global warming are discussed in upper elementary level and are commonly incorporated in movies. As such, student exposure and familiarity is much stronger in this context than others discussed in the study as shown for the empirical aspect of NOS. The topics about atomic structure and plate tectonics are discussed in middle school. However, these topics are still difficult topics in their abstraction, which could explain the lower percentages for NOS aspects within those contexts. It should be noted that the teaching of the issues in previous years was not similar in depth and time. For example, the issue about plate tectonics was visited only once in middle grades, while the atomic structure was discussed more than once. As for the issue about genetic engineering, it is discussed at the high school, and has not been discussed yet at the time of the study. Similarly, Khishfe (2012a) found that high school students elicited different response patterns in two scenarios addressing socio-scientific issues and the author interpreted this matter in relation to issue exposure and familiarity. They explained that students connected more to the issue about water fluoridation because the topic was more familiar and more likely to be experienced by these students in their everyday lives. The author also discussed how student familiarity might have come from the discussion of the issue within the media. In a similar fashion, Khishfe and Abd-El-Khalick (2002) found that participants showed more informed views of NOS in relation to the context of the dinosaur compared to the atomic structure. The author explained the results in terms of student familiarity and interest with the issue. Again, Lewis and Leach (2006) found that students engaged in more reasoned discussions and justifications when the socio-scientific issue was more familiar to them.

Personal relevance

Bektasli and Cakmakci's (2011) work supports the notion that consistency among different contexts and domains is limited. Their participants' ideas about reaction rate were incoherent within the physics and chemistry field. The authors attributed such outcome to the data, students' personal experience within the context and contextualised features of the given task. Tongchai, Sharma, Johnston, Arayathanitkul, and Soankwan (2011) have also confirmed the role of students' experience. As their participants gained more experience in physics learning, their consistency in implementing scientifically accepted models increased. In the context of atoms, plate tectonics, and genetic engineering, it could be argued that these topics do not have personal relevance since their discussion is limited to the school setting. In contrast, the topic of global warming is commonly discussed in the media and is more relevant to students' everyday lives.

Social constructivist perspective

To explain the inconsistency in students' views in relation to scientific and socio-scientific contexts, we examined the issue from a social constructivist perspective. According to Kolsto (2001a), one of the main frustrations experienced by lay people about socio-scientific issues is the perceived disagreements among scientists and other experts, which are interpreted by students as interests, personal opinion, and incompetence (Driver, Leach, Millar, & Scott, 1996; Kolsto, 2001a). Kolsto (2001b) further claimed that when students dealt with socio-scientific issues, their limited 'knowledge about the nature of scientific knowledge production they had picked up through schooling was not sufficient to make them understand or appreciate the uncertainties and the spread in the risk estimates in the relevant studies' (p. 897).

As noted earlier, Latour (1987) expressed the differences between scientific and socio-scientific issues as 'ready-made science' versus 'science-in-the-making.' The 'ready-made science' represent the final product and is regarded with a stable consensus among scientists (Bingle & Gaskell, 1994). This describes textbook science, while 'science-in-the-making' describes the science currently worked on in research. This issue of 'ready-made science' versus 'science in the making' was evident in the current study. One participant indicated that scientists are certain about the structure of the atom since it has been proven and uncertain about global warming and plate tectonics since they are yet to be proven, indicating that the latter is 'science in the making' and the former is 'ready-made science.' Kolsto (2001a) also noted that 'ready-made science' carries the undertone of positivist knowledge claims in contrast to 'science-in-the-making' that suggests a social constructivist view of contextual values for evaluating scientific knowledge claims.

Different domains of knowledge

Solomon (1993) distinguishes between two types of knowledge, the real-world knowledge constructed by children and the scientific knowledge that they attempt to learn in school science lessons. When children are challenged about the meanings that they use, they may slip from one meaning to another. Thus, students have two domains of knowledge and will have access to two different worlds of knowledge: the life-world and the scientific (Solomon, 1993). According to Solomon (1993), students store scientific knowledge in a different compartment from that of familiar life-world knowledge. We, therefore, propose that when students in the present study encountered scientific issues, they used the scientific domain of knowledge. For example, the conceptions relating to the atomic model correspond to scientific world in contrast to the informal world of everyday experience (Taber, 2000), whereas, students in the present study utilised the socialised life-world knowledge when they encountered the socio-scientific issues. And that access to the two worlds of knowledge can explain the inconsistency of students' informed views with the socio-scientific issues in comparison with scientific issues.

Students' individual differences

One explanation of the inconsistency in students' views can be related to the ability of students to recognise similarities in different tasks or contexts. Palmer (1993) found that students were unable to consistently apply the scientific conceptions. This made him conclude, as did Clough and Driver (1986), that students appeared to have a general problem in recognising similarities between contexts, even when the contexts were closely related. That relates to students' individual differences.

Implications and recommendations

In summary, findings from the research on learning of NOS suggested that learners' understanding of science content influences the way they construct and express their views within that science content. It is important to study that in order to understand how, if any, learners' views of NOS interact with their learning of science within a certain context, which will have implications on the way we teach NOS, a central component of scientific literacy. However, there is an initial step needed before we study the relation of NOS understanding to the context in which it is learnt. The primary need is to understand the relationship of NOS views to the science context/content when no formal explicit instruction is experienced. Such was the focus of this study.

It is essential that students have extensive practice in what it means to think like a scientist, especially since the world proves to be increasingly complex. The skills essential in science education are 'not only needed by scientists, but by every citizen in order to become a scientifically literate person able to function in a society where science has a major role and impact' (Huppert, Lomask, & Lazarowitz, 2002, p. 807). When students are exposed to everyday experiences (i.e. socio-scientific issues) that are linked to scientific concepts, it will logically aid students in applying their scientific reasoning in a consistent manner.

One of the recommendations of the study comes from the social constructivist perspective. To give students a richer and more informed view of science even the 'ready-made science,' we need to relate to the socially constructed nature of scientific knowledge, which would help students understand the foundation of the knowledge claims with which they are faced (Driver, Newton, & Osborne, 2000). As such, instruction that focuses on socio-scientific issues, which are considered as frontiers of science (Driver et al., 2000), communicates an authentic view of the socially constructed nature of scientific knowledge (Khishfe, 2012a).

Another implication relates to NOS instruction. The study represents an initial step in the exploration of NOS views that may or may not be consistent across different contexts. One implication points to the implementation of an explicit approach within a conceptual change framework in such a way that NOS instruction is integrated within different contexts/contents to address the inconsistency in students' views of NOS aspects (Khishfe, 2008).

Thus, it was important to address this issue in a consistent manner by exploring views in different contexts. This exploration was significant in helping us to gain more understandings into learners' views of NOS in scientific and socio-scientific contexts. Future research needs to study the nature of the inconsistencies in students' views of NOS within different scientific and socio-scientific contexts. And this will consequently aid us to better develop instructional approaches to improve learners' views, and improve the design of curriculum geared towards improving learners' conceptions of NOS.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Abd-El-Khalick, F. S. (1998). *The influence of history of science courses on students' conceptions of the nature of science* (Unpublished doctoral dissertation). Oregon State University, Corvallis, OR.

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(4), 417–436.

American Association for the Advancement of Science. (1989). *Project 2061: Science for all Americans*. New York, NY: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for scientific literacy*. New York, NY: Oxford University Press.

Bar, V., & Galili, I. (1994). Stages of children's views about evaporation. *International Journal of Science Education*, *16*(2), 157–174.

Baxter Magolda, M. B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development*. San Francisco, CA: Jossey-Bass.

Bektasli, B., & Cakmakci, G. (2011). Consistency of students' ideas about the concept of rate across different contexts. *Education and Science*, *36*(162), 273–287.

Belenky, M. F., Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind*. New York, NY: Basic Books.

Bingle, W. H., & Gaskell, P. J. (1994). Scientific literacy for decisionmaking and the social construction of scientific knowledge. *Science Education*, *78*(2), 185–201.

BouJaoude, S. (1991). A study of the nature of students' understanding about the concept of burning. *Journal of Research in Science Teaching*, *28*(8), 689–704.

BouJaoude, S. (2002). Balance of scientific literacy themes in science curricula: The case of Lebanon. *International Journal of Science Education*, *24*(2), 139–156.

Caravita, S., & Hallden, O. (1994). Re-framing the problem of conceptual change. *Learning and Instruction*, *4*, 89–111.

Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT Press.

Chi, M. T. H., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction*, *4*, 27–43.

Clough, E. E., & Driver, R. (1986). A study of consistency in the use of student's conceptual framework across different task contexts. *Science Education*, *70*(4), 473–496.

Cooke, N. J., & Bredin, S. D. (1994). Constructing naïve theories of motion on the fly. *Memory & Cognition*, *22*(4), 474–493.

Council of Ministers of Education, Canada (CMEC) Pan–Canadian Science Project. (1997). Common framework of science learning outcomes K to 12 [On-line]. Retrieved from http://204.225.6.243/science/framework/

Curriculum Council. (1998). *Curriculum framework for kindergarten to year 12 education in Western Australia*. Osborne Park, WA: The Council.

di Sessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, *10*(2-3), 105–225. Responses to commentary, 261–280.

di Sessa, A. A. (1996). What do 'just plain folk' know about physics? In D. R. Olson & N. Torrance (Eds.), *The handbook of education and human development: New models of learning, teaching, and schooling* (pp. 709–730). Oxford: Blackwell.

di Sessa, A. A. (1994). Speculations on the foundations of knowledge and intelligence. In D. Tirosh (Ed.), *Implicit and explicit knowledge: An educational approach* (pp. 1–54). Norwood, NJ: Ablex.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Philadelphia, PA: Open University Press.
Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312.
Fassoulopoulos, G., Kariotoglou, P., & Koumaras, P. (2003). *Consistent and inconsistent pupils' reasoning about intensive quantities: The case of density and pressure. Research in Science Education*, *33*(1), 71–87.
Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140.
Huppert, J., Lomask, S. M., & Lazarowitz, R. (2002). Computer simulations in the high school: Students' cognitive stages, science process skills and academic achievement in microbiology. *International Journal of Science Education*, *24*(8), 803–821.
Ioannides, C., & Vosniadou, S. (2002). The changing meaning of force. *Cognitive Science Quarterly*, *2*, 5–61.
Johnson, P. (1998a). Children's understanding of changes of state involving the gas state, part 1: Boiling water and the particle theory. *International Journal of Science Education*, *20*(5), 567–583. doi:10.1080/0950069980200505
Johnson, P. (1998b). Children's understanding of changes of state involving the gas state, part 2: Evaporation and condensation below boiling point. *International Journal of Science Education*, *20*(6), 695–709. doi:10.1080/0950069980200607
Khishfe, R. (2008). The development of seventh graders views of nature of science. *Journal of Research in Science Teaching*, *45*(4), 470–496.
Khishfe, R. (2012a). Nature of science and decision making. *International Journal of Science Education*, *34*(1), 67–100.
Khishfe, R. (2012b). Relationship between nature of science understandings and argumentation skills: A role for counterargument and contextual factors. *Journal of Research in Science Teaching*, *49*(4), 489–514.
Khishfe, R., & Abd-El-Khalick, F. (2002). The influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders views of nature of science. *Journal of Research in Science Teaching*, *39*(7), 551–578.
Khishfe, R., & Lederman, N. (2006). Teaching nature of science within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching*, *43*(4), 377–394.
King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass.
Kirbulut, Z., & Beeth, M. (2013). Consistency of students' ideas across evaporation, condensation, and boiling. *Research in Science Education*, *43*(1), 209–232. doi:10.1007/s11165-011-9264-z
Kolsto, S. D. (2001a). Science literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education*, *85*, 291–310.
Kolsto, S. D. (2001b). 'To trust or not to trust, … '-pupils' ways of judging information encountered in a socio-scientific issue. *International Journal of Science Education*, *23*(9), 877–901.
Kwen, B. H. (1996). Consistency and inconsistency in A level students' understandings of a number of chemical reactions. *Research in Science & Technological Education*, *14*(1), 55–66.
Latour, B. (1987). *Science in action*. Cambridge, MA: Harvard University Press.
Leach, J., Millar, R., Ryder, J., & Séré, M. (2000). Epistemological understanding in science learning: The consistency of representations across contexts. *Learning and Instruction*, *10*(6), 497–527.
Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*, 331–359.
Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*, 497–521.
Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 831–880). Mahwah, NJ: Erlbaum.
Lewis, J., & Leach, J. (2006). Discussion of socio-scientific issues: The role of science knowledge. *International Journal of Science Education*, *28*(11), 1267–1287.

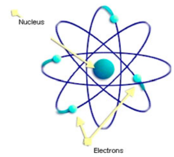
Linn, M., & Songer, N. (1991). Cognitive and conceptual change in adolescence. *American Journal of Education*, *99*(2), 379–417.
Matkins, J., & Bell, R. (2007). Awakening the scientist inside: Global climate change and the nature of science in an elementary science methods course. *Journal of Science Teacher Education*, *18*(2), 137–163.
McCloskey, M. (1983). Naïve theories of motion. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 299–324). Hillsdale, NJ: Lawrence Eralbaum Associates.
McDonald, C. V. (2010). The influence of explicit nature of science and argumentation instruction on preservice primary teachers' views of nature of science. *Journal of Research in Science Teaching*, *47*(9), 1137–1164.
Metz, K. E. (1991). Development of explanation: Incremental and fundamental change in children's physics knowledge. *Journal of Research in Science Teaching*, *28*(9), 785–797.
Millar, R., & Osborne, J. F. (Eds.). (1998). *Beyond 2000: Science education for the future*. London: King's College London.
Nakhleh, M. (1994). Student's models of matter in the context of acid-base chemistry. *Journal of Chemical Education*, *71*(6), 494–499.
Nakhleh, M. (2001). Theories or fragments? The debate over learners' naïve ideas about science. *Journal of Chemical Education*, *78*, 1107–1115.
National Research Council. (1996). *National science education standards*. Washington, DC: National Academic Press.
Osborne, R., & Cosgrove, M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching*, *20*(9), 825–838.
Palmer, D. (1993). How consistently do students use their alternative frameworks? *Research in Science Education*, *23*, 228–235.
Perry, W. G. (1970). *Forms of intellectual and ethical development in the college years: A scheme*. New York: Holt, Rinehart, and Winston.
Pozo, J. I., & Gomez-Crespo, M. A. (2005). The embodied nature of implicit theories: The consistency of ideas about the nature of matter. *Cognition and Instruction*, *23*(3), 351–387.
Prieto, T., Watson, R., & Dillon, J. (1992). Pupils' understanding of combustion. *Research in Science Education*, *22*, 331–340.
Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching*, *42*(1), 112–138.
Samarapungavan, A., & Wiers, R. (1997). Children's thoughts on the origin of species: A study of explanatory coherence. *Cognitive Science*, *21*(2), 147–177.
Smothers, S. M., & Goldston, M. J. (2010). Atoms, elements, molecules, and matter: An investigation into the congenitally blind adolescents' conceptual frameworks on the nature of matter. *Science Education*, *94*(3), 448–477.
Solomon, J. (1993). The social construction of children's scientific knowledge. In P. Black & A. M. Lucas (Eds.), *Children's informal ideas in science* (pp. 85–101). London: Routledge.
Taber, K. S. (2000). Multiple frameworks?: Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education*, *22*(4), 399–417.
Tongchai, A., Sharma, M., Johnston, I., Arayathanitkul, K., & Soankwan, C. (2011). Consistency of students' conceptions of wave propagation: Findings from a conceptual survey in mechanical waves. *Physical Review Special Topics*, *7*(2), 1–11. doi:10.1103/PhysRevSTPER.7.020101
Topcu, M., Sadler, T., & Yilmaz-Tuzun, O. (2010). Preservice science teachers' informal reasoning about socioscientific issues: The influence of issue context. *International Journal of Science Education*, *13*(18), 2475–2495.
Tytler, R. (1994). Consistency of children's use of science conceptions: Problems with the notion of 'conceptual change'. *Research in Science Education*, *24*, 338–347.
Tytler, R. (2000). A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: Dimensions of conceptual progression. *International Journal of Science Education*, *22*(5), 447–467. doi:10.1080/095006900289723
Watson, J. R., Prieto, T., & Dillon, J. S. (1997). Consistency of students' explanations about combustion. *Science Education*, *81*(4), 425–444.

Yang, F. (2005). Student views concerning evidence and the expert in reasoning a socio-scientific issue and personal epistemology. *Education Studies*, *31* (1), 65–84. doi:10.1080/03055690420003109 76

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, *86*, 343–367.

Appendix

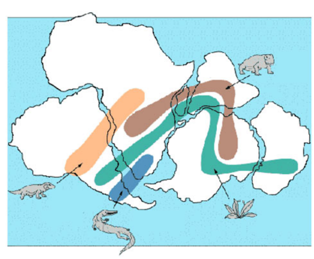
(1) The diagram below shows the atom as having a nucleus in the centre with electrons moving around it.
   (a) How did scientists determine this atomic structure?
   (b) Do you think scientists are sure about the structure of the atom? Explain what makes them sure or unsure.
   (c) Different scientists reached different shapes or models of the atom at different times. How can you explain that scientists came up with different models even though they were looking at the same data about the atom?



(2) The dinosaurs lived millions of years ago.
   (a) How do scientists know that dinosaurs really existed?
   (b) Do you think scientists are sure (certain) about the way dinosaurs look? Explain what makes them certain or uncertain.
   (c) Scientists agree that the dinosaurs became extinct about 65 million years ago. However, scientists disagree about what had caused this to happen. One group of scientists suggests that a huge meteorite hit the earth and caused the extinction. Another group of scientists suggests that violent volcanic eruptions caused the extinction. How is it possible for scientists to reach different conclusions when both groups are using the same data?

(3) Global warming refers to the warming of the Earth over the past 100 years.
   (a) How do scientists know that global warming is happening?
   (b) Do you think scientists are certain (sure) about global warming? Explain what makes them certain or uncertain.
   (c) Scientists disagree about what is causing global warming. Some scientists say that humans are warming the planet by the continuous burning of fossil fuels. Another group of scientists say that the causes for global warming are natural and are not related to humans. How is it possible for scientists to arrive at different conclusions when they are looking at the same data?

(4) Plate tectonics is the theory that the Earth's surface is made up of large pieces which are called plates. The size and position of the plates on which the continents (picture) are located change over time. The constant movement of the plates is responsible for the formation of mountains, islands, volcanoes, and earthquakes.
   (a) How do scientists know about the constant movement of plates?
   (b) Do you think scientists are certain (sure) about the theory of plate tectonics? Explain what makes them certain or uncertain.
   (c) Different scientists reached different theories about the Earth at different times. How can you explain that scientists came up with different theories even though they were looking at the same data about the Earth?



(5) Genetic engineering involves the techniques used by scientists to change and improve the basic composition of a living cell.
   (a) How do scientists know about the effects of genetic engineering?

(b) Are scientists certain (sure) about the effects of genetic engineering? Explain what makes them certain or uncertain.

Scientists disagree about the issue of genetically modified food. Some scientists say that this new technology can develop and improve food, with great benefits for humans and the environment. Another group of scientists say that there are harmful side effects of genetically modified food to humans, animals, and the environment. How is it possible for scientists to reach different conclusions even though they are looking at the same data about genetically modified food?