AMERICAN UNIVERSITY OF BEIRUT

TEACHING NATURE OF SCIENCE THROUGH THE DIFFERENT CONTEXTS: HISTORY OF SCIENCE, SCIENTIFIC INQUIRY, AND SOCIOSCIENTIFIC ISSUES

by
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ABSTRACT
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Research underscores the importance of understanding Nature of Science (NOS) to developing students' scientific literacy. This report specifically addresses the gaps identifies by McComas et al. (2020) who argued that the main contributor to inadequate understanding of NOS aspects is due to scarcity of effective NOS-focused instructional material. In response, this report focuses on designing six lesson plans tailored to facilitate effective teaching of NOS. The framework for designing the lesson plans is guided by a reflective, explicit, and contextualized approach that was extensively researched to be an effective approach to enhance students understanding of NOS. Accordingly, the lesson plans written were framed in different contexts: history of science (HOS); scientific inquiry (SI); and socioscientific issues (SSI). Lastly, a conclusion and recommendations that feed into a successful implementation of the lesson plans were discussed.

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CHAPTER 1

INTRODUCTION

“If a theory is verified, then it will never be proven wrong”. The student elaborates to explain that “a theory could be proven right by testing it in an experiment designed by a universal scientific method”. These statements were articulated by an eighth-grade student during a discussion on how science works and what scientists do. Clearly, the student expresses a naïve understanding of epistemology of science. This inadequate understanding can be attributed to multiple factors; however, many relate it to insufficient classroom experiences that negates science epistemology. As a result, students will perceive science as an absolute body of knowledge constructed via a universal scientific method devoid of creativity, imagination, subjectivity, or any social influence. Unfortunately, as we will discuss later in this report, research continuously concluded that a naïve view is held by the majority of students and teachers worldwide (Abd-El-Khalick & Boujaoude, 2003; Bell et al., 2011; Driver et al., 1996; Eastwood et al., 2012; Khishfe, 2020; Lederman, 1992; Solomon et al., 1996; Walker & Zeidler, 2007).

Before presenting the issue of inadequate understanding of science epistemology, and discussing the approaches that were found best to teach it, allow us to start with a brief summary of what this construct entails. This chapter will also conclude by stating the problem we are trying to solve and the purpose of the report.

Science as A Way of Knowing

According to Lederman (1992), epistemology of science and science as a way of knowing are referred to as nature of science (NOS). Although the construct of NOS has been extensively researched and highly ranked for decades as a fundamental element of scientific literacy (BouJaoude, 2002; Driver et al., 1996; Khishfe, 2017), however, contrary to what a researcher might assume, an agreement over a generalizable definition does not exist (Abd-El-Khalick, 2012; Lederman, 2007). Nevertheless, there exists general agreements over key aspects of NOS, rather than a general definition. According to Abd-El-Khalick et al. (1998), these aspects include science being (1) tentative as it is subject to change; (2) empirical as it's based on and/or derived from observation of the natural world; (3) theory laden; (4) partially a result of human inference, imagination and creativity; and (5) socially and culturally embedded. The distinction between laws and theories, and between observations and inferences are further argued to be two additional key aspects of NOS.

The importance of NOS is highlighted by worldwide reform documents that promote the construct as an essential dimension to achieve scientific literacy. The National Research Council (NRC) (2013) emphasized the importance of teaching and learning NOS and identified it as one of the K-12 goals of science education. They further recognized its understanding as a condition for a student to achieve scientific literacy. Additionally, the American Association for Advancement of Science (AAAS) (1993) recommended giving science epistemology a prominent place in science classroom instruction, if scientific literacy was is to be one of its aims.

Features to a Successful NOS Instruction

A significant body of research investigated various approaches to teach NOS. The effectiveness of an instructional approach was contributed to two major forms of instruction, namely the explicit-reflective and the contextualized. Abd-El-Khalick and Akerson (2004) explain that an explicit approach refers to educational practices in which the elements of NOS are distinctly articulated and clarified as a learning objective and a desired cognitive outcome. Whereas the “reflective” aspect of the instruction refers to creating opportunities for students to analyze the activities and establish connections between their experiences and the desired NOS aspects to make inferences about the epistemology of science. On the other hand, the term context refers to the settings in which the NOS instruction is delivered (McComas et al., 2020). A contextualized NOS instruction is one that is bound to science content (Clough, 2006). McComas et al. (2020) discussed three instructional contexts that are well-suited to promote students’ NOS understanding and they are outlined as follows: (1) history of science (HOS), (2) scientific inquiry (SI), and (3) socioscientific issues (SSI).

Statement of the problem

Despite the widespread recommendations of having NOS understanding as an aim to science curricula in numerous studies and educational reforms, a review of the literature concludes that this goal has not been realized. Students, as it has been observed, lack an adequate understanding of the construct (Bell et al., 2011; Eastwood et al., 2012; Khishfe, 2020; Walker & Zeidler, 2007). Notably, this generalization is not disputed in Lebanon. Research done in the context of the Lebanese science education shows that students’ and teachers’ understanding of the construct resonates with the general trend worldwide (Yacoubian & BouJaoude, 2010; Abd-El-Khalick & Boujaoude, 2003). BouJaoude (2002) further investigated elements of scientific literacy in the Lebanese curriculum to concluded that “science as a way of knowing”, i.e. scientific epistemology, was clearly mentioned in the broad objectives of the science curriculum. Nevertheless, the specific content and the requirements of the curriculum did not recommend the teaching and learning of NOS. Thus, concluding that the curriculum does not support students nor teachers in developing an accepted understanding of the construct.

McComas et al. (2020) argued that the main factor contributing to the failure of achieving the desired understanding of NOS is the lack of effective NOS-focused instructional material. They further discussed that science teachers rely on textbooks and other supporting material that lacks focus on NOS. Thus, discouraging any integration of the construct in the unit plans and everyday lessons. Moreover, Wahbeh and Abd-El-Khalick (2014) contributed to this line of research by concluding that the lack of resources, such as lesson plans and instructional activities, impeded educators from teaching the construct. Data from interviews with teachers provided a strong evidence that lacking NOS-related instructional resources aligned with their lessons is a major contributor to keeping NOS discussions outside their classrooms. They further inferred that the availability of such resources facilitated transmission of NOS understanding (Wahbeh & Abd-El-Khalick, 2014). Finally, Clough (2006) argues that teachers are not encouraged to plan for NOS understanding to be an additional cognitive objective, especially when non-entangled with scientific content, as it is perceived as a distraction from the scientific content they prioritize to teach.

In light of this reality, and in an attempt to support educators' efforts to teach NOS in the Lebanese curriculum, we find ourselves compelled to provide effective resources in the form of lesson plans aligned with grade 8 chemistry content. To this end, the goal is to equip the teachers with materials that facilitates NOS instruction within their taught curriculum in an attempt to enhance students' NOS conceptions, hence, promote their scientific literacy.

The purpose of the Report

This report is based on the premise that the scarcity in instructional tools is a major factor that contributes to neglecting NOS by teachers inside the classroom. Thus, the purpose is to provide instructional material that will facilitate the teaching and learning of NOS. From this stand point, the aim is to provide grade 8 chemistry teachers with a booklet that comprises six detailed lessons plans that are aligned with the Lebanese curriculum, in addition to their respective student handouts that aim to teach NOS aspects in three different contexts, namely history of science, scientific inquiry, and socioscientific issues. Grade 8 is particularly targeted in this report since this stage does not involve the stress of preparing for any official examinations that are assessment driven. Hence, teachers might feel encouraged to employ more time to teach ideas that are not typically evaluated in official exams. The scope of this report limits us from further designing lesson plans with various grade levels, however, we strongly believe it's important to design NOS instructional material in the contexts of chemistry, biology, and physics in all grade levels to systematically build a wholistic approach to teach NOS.

The next section of this report will present a literature review on the two main constructs grounding this report: (1) Nature of science, including its definition, and the current understanding among teachers and students; (2) Instructional features that contribute to successful NOS instruction, specifically the explicit-reflective and the contextualized approach.

CHAPTER 2

LITERATURE REVIEW

Marking NOS as a major aspect of scientific literacy has contributed to generating extensive research around the construct. Most of the studies have been directed towards defining a framework for NOS, exploring students' and teachers' beliefs about the construct, and investigating instructional approaches that are believed to be most effective in teaching it. Accordingly, the basis of this report is built on three interrelated elements. The first is the framework of NOS as proposed by Lederman (2007), known as the consensus model. The second is the explicit and reflective approach deemed to be effective, and the third are the common instructional contexts that were commonly used in research as vehicles to teach NOS including history of science, socioscientific issues, and scientific inquiry.

Nature of Science

Before exploring the controversy evident in the literature regarding NOS, it is important to establish some general parameters for the construct. According to Lederman (1992), NOS refers to the epistemology of science, or in other words, it describes science as a way of knowing. Although the construct of NOS has been extensively researched and highly ranked for decades as a fundamental element of scientific literacy, however, in contrast to what a researcher might assume, an agreement over a generalizable definition does not exist (Lederman, 2007; Abd-El-Khalick, 2012). An exact definition of the construct, or what it entails, is a subject of debate within the research community.

In an attempt to converge the different perspectives of what the construct should entail, and to reduce the controversy over the matter, Lederman, along with a group of researchers, formulated a list of general aspects of NOS. According to Lederman (2007) and Abd-El-Khalick (2012), there is more agreement rather than disagreement when it comes to the aspects formulated in what Abd-El-Khalick calls the “consensus framework” or “consensus model”. Among these aspects are the characterization of scientific knowledge as being tentative rather than a definite body of knowledge; empirically based on observations; subjective; partially a result of human inferences, creativity, and imagination; and socially and culturally embedded. In addition to the aforementioned, the distinction between observations and inferences and between theories and laws were agreed to be additional aspects.

The consensus model, distilled by Lederman, has been subject to criticism as it is regarded by many as narrow and encapsulating regarding the notion of epistemology of science. Others advocated sidestepping the model to reside directly to scientists and scientific practices to understand what science is. Hodson and Wong (2014), expressed the need to refine the model as they argued that it overlooks the voices of practicing scientists when they should be the primary source of our understanding of NOS. Additionally, they accused the model of being philosophically naïve and unable to reflect the complexity of the scientific endeavor. In a different position paper, Duschl (2013) argued for students’ immersion in cognitive, epistemic, and social practices of science that may occur through extended units of inquiry and longer teaching sequences as a condition to learn NOS. The author asserts that figuring out what NOS is about must involve students in first-hand apprentice programs in laboratories or field settings, in contrast to consensus based instructional methods that may aim to establish links to dimensions of NOS during lessons and activities.

Furthermore, Allchin (2011) argues that the consensus model omits aspects that are essential to scientific literacy. He argues that for individuals to achieve scientific literacy, they need to have a good understanding of aspects that extend past the list of the consensus model. According to Allchin, the list needs to be more comprehensive to include credibility, gender biases, peer review, conflict of interest, and other aspects that the author describes as core to the scientific endeavor.

In addition to what was mentioned, Irzik and Nola (2011) argued that the consensus view fails to appreciate the various disciplines that constitute the realm of science. In a similar vein, Rudolph (2000) calls for dismissing the universal views of NOS promoted by the domain-general approach of the consensus framework, to adopt a domain-specific views of nature of science. The author contends that such a transition is important for students to appreciate the particularities of the different disciplines in science, and would facilitate the understanding of the complex diversity of the scientific endeavor.

Amid all the controversy surrounding the construct of NOS, Abd-El-Khalick (2012) argues that the consensus model is a credible and pragmatic framework for several reasons. Firstly, the author contends that NOS is a philosophical concept that should be studied from a philosophical and historical approach, rather than sociological one. Privileging the perceptions of scientists to construct our understanding of NOS might not be valid since scientists themselves do not engage and reflect on their day-to-day scientific practices from an epistemological lens, nor may they have access to epistemic theoretical grounds to do so. Additionally, the author disputes the arguments that claim the simplicity of the NOS aspects by referring to empirical research that does not support such a concern. According to literature, and irrespective of the assessment tools, it has been consistently documented that there are significant challenges in transforming students’ and teachers’ views into adequate and meaningful and interconnected concepts of NOS.

Secondly, in response to Duschl (2013), Abd-El-Khalick (2012) explains that claiming that NOS understanding can only be acquired through apprenticeship and first-hand science practices conflates NOS with scientific inquiry and is unfounded and may be unfruitful. According the author, the approach has been tested by engaging pre-college students in the Harvard Physics Course and failed to significantly transform students views on NOS. Similarly, Burgin and Sadler (2016) tested the impact of an authentic engagement in a summer apprentice program to document only minor changes in students’ views when their experiences were devoid of explicit and reflective discussions on the NOS aspects. This being said, we do not claim that extended engagement in scientific practices and inquiry are not useful for science education or learning NOS, however, they may serve as another instructional method that should be incorporated in the quest of teaching NOS.

Thirdly, the level of generality at which the NOS aspects are addressed in the consensus framework allows them to explain a wide scope of scientific practices from an epistemological lens. For example, and in response to Allchin (2011), gender biases, credibility, and peer review, can be explained through dimensions of subjectivity and social and cultural embeddedness of science. I believe that the framework encourages in-depth explorations of each aspect going beyond the superficial understanding. Abd-El-Khalick (2012) recommends examining the aspects with substantive depth for a nuanced comprehension of what the scientific endeavor entails.

Lastly, the author explains that advocates of domain specific NOS framework have yet to justify how the consensus framework does not apply to specific disciplinary contexts. He further argues that the current consensus framework may provide the foundational understanding which can be further nuanced through context specific explorations, thus transforming students' understanding to become more sophisticated regarding the dimensions of NOS. It's also argued that domain-specific and domain-general approaches are not two competing approaches, but complementary and synergistic. Advocates of domain-specific NOS frameworks should embrace students understanding of NOS views elucidated by the domain-general consensus framework as they will facilitate the development of the deeper and nuanced context-specific views of science (Abd-El-Khalick, 2012).

In addition to the counterargument articulated above, we concur that the consensus model can provide a foundational understanding of science epistemology and can be addressed in an increasing level of sophistication along a continuum from being simple, uncontroversial, and general in the elementary level, to becoming more complex and specific to scientific contexts while taking into considerations the learners developmental levels. Furthermore, from a utilitarian point of view, and in reference to extensive research done on the matter, dimensions of the consensus framework are proved to be accessible to K-12 students and can be utilized by teachers to promote students understanding of NOS (Abd-El-Khalick, 2012).

Students' Understanding of Nature of Science

Despite the worldwide focus of reform documents and curricula on the construct of NOS, a review of the literature concludes that this goal has not been realized as both students and teachers do not possess an adequate understanding of NOS (Bell et al., 2011; Abd-El-Khalick & Boujaoude, 2003; Eastwood et al., 2012; Khishfe, 2020; Lederman & Lederman, 2014; Walker & Zeidler, 2007). Thus, we will provide a literature review that shows consistent findings across diverse contexts and measuring instruments. Additionally, the recent studies presented may offer relevant context to our report and further demonstrates the persistent inadequacy in students' understanding over decades.

Lederman (1992) reviewed empirical studies, both quantitative and qualitative, to explore students' and teachers' conceptions of NOS. He reached an overwhelming conclusion that students exhibited inadequate views of NOS. The finding becomes particularly significant as studies employing various assessment instruments consistently produced the same findings. Among these studies, Cooly and Klopfer (1963) established the first paper-based instrument to assess students' conception of science in the United States. They utilized their Likert-scale Test on Understanding Science (TOUS) instrument to conclude that most high-school students did not hold an adequate understanding of the scientific endeavor. Following these initial explorations using TOUS, Rubba and Andersen (1978) developed and utilized the Nature of Scientific Knowledge Scale (NSKS) to gauge students' conceptions of the NOS. Their findings indicated that high-school students viewed scientific knowledge as irrefutable and is the absolute truth. Additionally, students viewed theories and laws in a hierarchal relation as they believed that theories are promoted to become laws. Furthermore, Lederman (1992) concludes that instructional activities that stress inquiry, problem solving and frequent higher-level questioning may be related to the desired changes in students' views.

Following the extensive literature review conducted by Lederman (1992), which aimed to explore students' and teachers' views on NOS, a subsequent investigation by Abd-El-Khalick and Lederman (2000) assessed the influence of a history of science courses on undergraduate university students' views of NOS. During the first week of the term, and prior to instruction, NOS profiles of 181 students were examined by administering NOS questionnaires in addition to individual interviews conducted with 22% of the participants. The questionnaire comprised nine open-ended questions that measured participants' views on several NOS aspects including the tentative, empirical, and the subjective aspect of NOS, in addition to participants' views of the scientific method, their ability to differentiate between scientific theories and laws. Following the questionnaire, semi-structured interviews were conducted to validate participants' responses and avoid misinterpretations.

Prior to instruction, the data helped the authors conclude that almost all participants exhibited a naïve understanding of the measured NOS aspects. Firstly, almost 90% of the participants believed that scientific knowledge is "proven true" and is absolute. Secondly, they perceived science as a body of content knowledge that is an outcome of facts that provide a right or wrong answer, rather than being validated and influenced by human interpretation of empirical data. Thirdly, majority of the students failed to attribute scientific claims to scientists' disciplinary and educational backgrounds, personal experiences, opinions or philosophical assumptions. Fourthly, 85 % of the participants who sat for semi structured interviews expressed that scientists follow a universal scientific method which is based on an organized set of procedures. Fifthly, consistent with their perception of science being absolute, the majority of the participants expressed that scientific laws have been extensively proven, and will not change as they are scientifically true. Additionally, the participants held a hierarchal view of theories and laws as they argue that a law becomes a theory when there is proof that its consistently proven right. Hence, providing a compelling evidence that most of the participants held naïve views of the NOS aspects.

In a more recent study, Kang et al. (2005) investigated the NOS beliefs of 1702 Korean students across grade levels (grades 6, 8 and 10). Apart from attempting to explore students' beliefs about science, the investigation provided a lens to examine whether there is a relationship between students' beliefs and their science experiences across grade levels. The authors adopted a new instrument, the views of science-technology-society (VOSTS), that was developed by Aikenhead et al. (1989). The instrument was of a multiple-choice format with four items to assess students' understanding on: (1) the purpose of science; (2) the definition of scientific theory; (3) tentativeness of scientific theory; and (4) origin of scientific theory. Participants also justified their choice by responding to open-ended questions on each item.

Only a small number of participants, regardless of their grade level, demonstrated an acceptable understanding of NOS. Firstly, the findings concluded that the majority of the students adopted an instrumentalist view of science. Secondly, most participants defined theories as facts or the absolute truth that have been tested extensively by experiments. Thirdly, the majority of the students believed that theories develop over time, however, after scrutinizing their rationales in the open-ended questions, it was inferred that their views were rather naïve about the concept of tentativeness.

On the other hand, in the Lebanese context, Abd-El-Khalick and BouJaoude (2003) investigated students' definition of science, and their views of its purposes and uses. The participants were middle-school students from varying socioeconomic backgrounds. Data was collected by asking the participants to respond to an open-ended questionnaire in addition to conducting semi-structured individual interviews. The data indicated that most participants had a restricted view of science and perceived it as a subject to be studied in school and disconnected from real life. It was viewed as a body of knowledge that gives information about nature around us, and its purpose is to prepare them for future careers. For most of the participants, scientific knowledge and skills are to be utilized in academics rather than real life settings (Abd-El-Khalick & BouJaoude, 2003). The paper's findings demonstrate the consistency with the literature findings regarding the inadequacy of students' understanding.

In another significant study done in Turkey, Dogan and Abd-El-Khalick (2008) explored more than 2000 students' conceptions of NOS. The variables investigated in this study included participants' gender, geographical region, the socioeconomic status (SES) of their city and region, in addition to the students' SES and parents' level of education. The researchers asserted that Turkey is an ideal context to such exploration, since it literally bridges two continents and encompasses both western and eastern cultural influences.

The population of this study comprised grade 10 high school students who have elected secondary science to be part of their studies. The sample of students was selected from the seven geographical regions in the country. A modified version of VOSTS was used to gauge students' understanding of epistemological issues of scientific knowledge and its development. They concluded that the majority held a naïve understanding of most NOS aspects. However, the situation was not entirely bleak. Exceptions were found in students' views of tentativeness of science, and the relationship between classification schemes and reality. The majority of students had an informed view of the mentioned dimensions, though the scrutiny of data proved it to be inconsistent. 68.2 % of the students held informed views of the tentative aspect of NOS while simultaneously believing that a scientific law, when repeatedly tested, can be “proven” correct. The latter view of knowledge is inconsistent with their informed view of tentativeness. Similarly, 58.8 % of the participants held informed understanding of the relationship between classification schemes and reality. However, participants also viewed scientific models as replicas of reality, assuming that these models are verified by scientists who repeatedly have proven them to be true. Such a contradiction highlights inconsistency in participant’s understanding, particularly since models and classification schemes, as scientific constructs, share basic similarities.

One of the more significant findings of this exploratory study was the relation between understanding of NOS and economical, educational, and cultural backgrounds. Notably, quantitative evidence helped the researchers conclude that within the minority of students who have informed views, those with western culture influences and higher SES seem to dominate this minority. Students with more educated parents, coming from cities and households with higher SES which correlates with regions with European-like cultures were more likely to exhibit informed views on some targeted aspects compared to their counterparts. The authors attributed this observation to differences in epistemological perspectives that may be inherent to these communities. They explained that an informed understanding of NOS aligns with a skeptical, critical, and creative view of knowledge. This approach contrasts with the authoritarian view that is more likely to prevail Eastern regions with lower SES (Dogan & Abd-El-Khalick, 2008)

Moreover, Khishfe (2017) conducted a qualitative case study in six schools in the Kingdom of Saudi Arabia that aimed to investigate students' understanding of NOS and their argumentation skills in the context of four socioscientific issues. The author particularly investigated students' beliefs of the tentative, empirical, and subjective aspects of NOS. The socioscientific issues were presented as scenarios, then, they were followed by two sets of open-ended questions. The first was used to examine their argumentation skills, the second encouraged the students to show their conceptions of NOS. The results showed consistency with previous findings regarding the level of understanding of NOS. The majority of the students were not capable of formulating a well-developed argument and held inadequate understanding of the targeted NOS aspect prior to explicit instruction on the matter.

Overall, the findings of more recent studies about students' views of NOS support the earlier research done on the matter. In the absence of a systematic intervention to teach NOS, students will not have an accepted view of the construct (Lederman & Lederman, 2014). Accordingly, we turn our attention to teaching NOS and designing instructional approaches that would help us reach a desired outcome. In the following pages, we will discuss different teaching strategies, namely the explicit and reflective approach and three instructional contexts to teach NOS.

Nature of Science Instruction

Researchers generally agree that students have a simplistic view of NOS. In an attempt to promote their understanding of the construct, the effectiveness of various instructional approaches has been investigated. Among those approaches are the explicit-reflective approach and the contextualized approaches. By explicit, we refer to educational practices in which the elements of NOS are distinctly articulated and clarified as a learning objective and a desired cognitive outcome (Abd-El-Khalick & Akerson, 2004). On the other hand, the term context refers to the settings in which the NOS instruction is delivered (Abd-El-Khalick & Akerson, 2004; McComas et al., 2020). The following part of the report will explore the literature to provide a discussion of their effectiveness and their limitations in teaching NOS for the benefit of our report.

Explicit and Reflective Approach

Evidence collected across decades of research highlights the importance of designing explicit approaches to teach NOS. Before reaching this conclusion, it was assumed that students would automatically develop their NOS views by engaging in inquiry-based activities or by exercising their science process skills. However, research findings do not support what used to be an underlying belief that NOS can be taught implicitly. On the other hand, substantial evidence has been collected to advocate the importance of an explicit and reflective approach instead. Abd-El-Khalick and Akerson (2004) discussed that explicit entails intentionally targeting NOS as a cognitive learning outcome similar to theories and laws of science taught in class.

On the other hand, a reflective approach refers to students constructing their own knowledge about epistemology of science in contrast to memorization of content taught (Abd-El-Khalick & Akerson, 2004; McComas et al., 2020). A reflective approach entails providing opportunities for students to analyze their activities and make connections to their experiences and the work of scientists to formulate conclusions about epistemology of scientific knowledge (Abd-El-Khalick & Akerson, 2004; McComas et al., 2020). The focus on reflection is rooted in constructivists theories of knowledge that acknowledge learning as an active process where students use their prior experiences to construct their own knowledge. Nonetheless, McComas et al. argue that this needs to be teacher-led to avoid students reaching wrong conclusions (McComas et al., 2020).

In an attempt to investigate the effectiveness of the explicit and reflective approach in comparison to implicit instruction, Khishfe and Abd-El-Khalick (2002) conducted a study involving 62 sixth graders split into two classes. The study focused on the tentative, empirical, inferential, imaginative, and creative aspects of NOS. The first class, known as the intervention group, was exposed to an explicit and reflective inquiry-based instruction to teach NOS. In contrast, the second class, named the comparison group, was engaged in the same inquiry-based activities without any explicit NOS instruction. Both groups experienced the same activities and discussions to the best extent possible, however, the intervention group was exposed to discussions that targeted the NOS aspects at the end of each activity, and they were encouraged to reflect on the aspects in relation to the activity done.

To assess participants views of the NOS aspects, an open-ended questionnaire was employed followed by individual interviews before and after the intervention. Prior to instruction, there was no substantial difference between the views of both groups towards NOS. The majority of students in both groups held naïve understanding of target NOS aspects. Moreover, no changes were observed pre and post intervention in the implicit group. However, a significant improvement was documented in post instruction views in the intervention group. All participants in the intervention group showed a substantial improvement in their beliefs across the targeted NOS aspects. The results proved that when NOS aspects are regarded as a cognitive learning outcome woven in inquiry-based activities, students' views of NOS can be positively influenced.

The students did not enhance their views as a result of engagement in inquiry without referral to NOS (Khishfe & Abd-El-Khalick, 2002).

Even though there are many studies that favored the explicit and reflective instruction to teach NOS, researchers were still interested in studying different modes of implicit instructional approach. Based on the assumption that authentic experiences in science might influence the epistemological beliefs without any additional instructional support, Burgin and Sadler (2016) conducted a comparative study to investigate the impact of three different approaches for NOS instruction in a summer apprentice program. All the participants were placed in science laboratories to get engaged in real world science work. However, in addition to the authentic engagement in science work, a second group of students had reflective discussions that were focused on NOS, and a third group got engaged in explicit NOS teaching in addition to reflective discussions on the matter.

Participants responded to Views of Nature of Science questionnaire (VNOS) administered before and after the apprentice program. Qualitative data was further collected from structured interviews from students in different mediums to provide justification to their answers on the open-ended questions. The data showed minor enhancement in students’ beliefs of NOS when only engaged in authentic science work coupled, or uncoupled, with reflection opportunities. However, when the instruction is both explicit and reflective while embedded in authentic science work, their learning outcomes on epistemology was maximized. This demonstrates the necessity of explicit and reflective engagement to promote informed NOS beliefs (Burgin & Sadler, 2016). Additionally, the data revealed that students who exclusively worked with scientists in the apprentice program in the absence of any sort of NOS instruction showed some negative changes in their beliefs. This observation resonates with McComas et al. (2020) who argued that misconceptions may rise in the absence of teacher led instructions on NOS, and thus, might counteract the intentions behind the engagement.

In a different study conducted by Bell et al (2011), they investigated the influence of explicit versus implicit instruction in addition to the context of NOS instruction on preservice science teachers. The contextualized/decontextualized instruction is an additional factor investigated in this study, and will be discussed in more details in following sections of the report. Nevertheless, the data provides more insight to the importance of explicit nature of instruction for NOS, and more implications to the contextualized/decontextualized mediums. The participants were sorted into four groups. Group (1) participants were engaged with explicit NOS instruction contextualized with global warming as a SSI; group (2) participants were engaged with explicit NOS decontextualized of scientific content; group (3) participants were engaged with global warming as a SSI in the absence of NOS instruction; and group (4), the control group, were engaged in process skill-based activities that omitted discussions on NOS and SSIs.

Data was collected pre and post the interventions and the sources included answers to open-ended questions on a modified version of VNOS, semi-structured interviews of six selected participants, in addition to coursework notes and classroom artifacts. The results indicated a substantial positive change in preservice teachers' beliefs of NOS when the construct was explicitly taught, despite of contextualization. In contrast, the data showed non-significant changes in NOS views of teachers who were engaged in implicit NOS instruction, also, regardless of contextualization. The results of the experiment capitalizes on the necessity of having explicit approach to teach NOS.

The general picture that is inferred from the findings indicates that it does not make a difference whether the instruction to teach NOS is contextualized or non-contextualized when the aim is to promote the understanding of NOS aspects. The results resonate with findings from Khishfe and Lederman (2006) who recorded positive changes in students' beliefs in integrated and non integrated mediums to teach NOS. However, this happens to be a controversial topic due to the existence of a significant body of knowledge that necessitates the contextualization of NOS instruction (Clough, 2006; Khishfe & Lederman, 2006; Bell et. al, 2011). For the purpose of this report, further discussion of the topic of contextualization will be posed in the following part of the report.

Contextualized Versus Decontexualized Explicit Instruction to Teach NOS

The context of NOS instruction is an important aspect to teaching the construct. The literature is rich in examples of NOS activities such as the "black-box", "tricky tracks" and other puzzle games that were designed with the intention to explicitly and reflectively teach students about particular aspects of NOS (Lederman & Abd-El-Khalick, 1998) devoid of scientific content. Those activities are labeled as decontextualized. In a theoretical paper, Clough (2006) argues that decontextualized NOS instruction may help students establish their foundations of accepted NOS understanding, however, those decontextualized experiences may be dismissed as non authentic scientific work. He further elaborates that the teacher would need to put some extra effort to prove to the students that this resembles the scientific endeavor. Finally, he contends that science teachers are unconvinced of the need to pin NOS understanding as a cognitive objective as the decontextualized approach is percieved as a distraction from their primary job of teaching science content. Accordingly, thoughtful consideration of the curriculum and integrating NOS lessons with science content with an explicit and reflective approach is believed to play a significant role in turning teachers' and students' attention to important NOS issues (Clough, 2006).

The impact of contextualization on students' understanding of NOS was investigated by Khishfe and Lederman (2006). Two grade 9 sections were randomly assigned for treatments. The first section experienced explicit and reflective NOS instruction integrated within a controversial scientific issue, i.e. global warming. This contextualized approach intended to teach students targeted NOS aspects in addition to the scientific content of global warming simultanously. Whereas the second section experienced explicit and reflective NOS instruction as stand-alone, devoid of any scientific content, scattered between science lessons without making any link to global warming. The non-integrated (decontextualized) activities were adopted from Abd-El-Khalik and Lederman (1998) designed for explicit and reflective instruction to NOS target aspects.

Participants' beliefs of the targeted NOS aspects were assessed by using an open-eneded questionnaire coupled with semi-structured interviews pre and post the intervention. The data revealed that both treatments resulted in promoting participants' beliefs of NOS. A closer scrutiny of the data helped infer that the contextualized appraoch resulted in more improvement to informed views whereas the decontextualized resulted in more improvement to transitional views. Accordingly, the overall findings suggested that the explicit and reflective approach promoted students' understanding of target NOS aspects regardless of whether it was contextualized within a SSI or taught as stand alone, i.e. decontextualized. There is no superiority of one approach over the other.

The authors discussed that the results do not suggest that NOS instruction should not be entangled with science content, however, they suggest that contextualizing NOS instruction within a SSI is as effective in promoting NOS aspects as decontextualized instruction.

Along the findings of Khishfe and Lederman (2006), Bell et al. (2011) reached a similar conclusion when the context of teaching NOS instruction was investigated. As reviewed in the preceeding part of the report, the results indicated a substantial positive change in preservice teachers’ beliefs of NOS when the construct was explicitly taught despite of contextualization. Teaching NOS in the context of a SSI was equally effective as teaching it devoid of science content. However, its important to point out that the participants who received instructions embedded within the context of global warming (SSI) produced apparent gains in their ability to use their general knowledge of NOS aspects in decision making. This might not be a primary objective when teaching target NOS aspects is the aim, however, it is definetly a desired outcome of integrating NOS instruction within SSI context.

In the current report, and for the mentioned reasons above, we adopt a contextualized approach to teaching NOS. To this end, we wish to introduce the three frameworks of contextualization to teaching NOS. Those frameworks include scientific inquiry (SI), history of science (HOS), and soscioscientific issues (SSI). McComas et al. (2020) argue that the mentioned mediums provide valuable opportunities to teach NOS. The following part of the report will focus on defining the contexts of interest, and provide a literature review to capitalize on their importance for teaching NOS.

Scientific Inquiry. Numerous studies emphasize the importance of inquiry as a pedagogical approach to teaching NOS. In particular, Lederman (2013) highlights the significance of inquiry experiences, arguing that they provide valuable opportunities for students to reflect on various aspects of NOS. McComas et al. (2020) further elaborate that teaching and learning NOS through inquiry-based instructions can manifest in various forms. For instance, it could occur through project-based learning, where students are immersed in inquiry cycles to answer their research questions as commonly observed in science fair projects. Additionally, other forms might manifest in shorter laboratory activities tailored to teach specific scientific content and skills. Inquiry-based teaching and learning can also take place in short classroom activities that actively engage students in the learning process (McComas et al., 2020).

In a study conducted by Yacoubian and Boujaoude (2010), the researchers investigated the influence of an explicit and reflective discussion following inquiry-based laboratory activities on the understanding of NOS aspects. The authors argue that laboratory activities that use inquiry as a pedagogical instruction (inquiry-based instruction) provide students with a first-hand authentic experience of how scientists work, thus, establishing a good context to teach NOS. However, they further explain that inquiry on its own is not sufficient to promote NOS aspects. An explicit and reflective approach to discuss target NOS aspects is necessary to promote students' understanding.

The researchers engaged 38 students in grade 6 from a Lebanese public school and explored the improvement in their views of the tentative, empirical, subjective, and social aspects of NOS. The student sample was split into a control group and an experimental group. Both groups were exposed to the same set of 8 inquiry-based laboratory activities. The lessons addressed a range of topics including freezing point, melting point, masses, chemical change, characteristics of acids and bases, oxidation of steel, and digestion of starch. However, NOS-specific reflection questions were only posed at the end of the experimental group activities. This was followed with a reflective discussion in class on the NOS aspects investigated. On the other hand, the activities in the control group had questions only on the results of the laboratory work.

Various sources of data informed the researchers of the efficacy of the intervention. Firstly, data was collected in a pre/post manner using an open-ended questionnaire (POSE) adopted from Abd-El-Khalick (2002). Secondly, video recordings from classroom were analyzed in both the controlled and experimental groups. Thirdly, semi-structured interviews were held with particular students chosen from each experimental group. Initially, students from both groups expressed naïve understanding of the target aspects of NOS. The results further inferred that students in the control group who did not experience an explicit and reflective discussion failed to enhance their inadequate conceptions. Furthermore, the results indicated that an explicit approach following an inquiry-based laboratory activity enhanced students' understanding of the targeted NOS aspects. A conclusion that encourages our decision to design an inquiry-based lesson in an attempt to reach our goal of promoting student views of NOS.

Peters (2012) studied the effectiveness of teaching NOS through an explicit reflective instructional approach in comparison to an implicit one. He further explored the possible mechanism of students learning NOS and content knowledge simultaneously. The author plains the theory of self-regulation as a foundation to the explicit and reflective instructional approach. He refers to Zimmerman (2000) to explain the self-regulatory approach as one that recognizes students as metacognitively active and reflective participants when involved in their own learning process which comprises three phases. The forethought phase where students arrange their prior knowledge that might help them solve the problem they are facing. This is followed by the performance phase, where students get engaged in the inquiry task and access their prior knowledge to develop new skills and understanding. In the self-reflection phase, the students compare the outcome of their work with a standard to see how far they were successful. Consequently, the intervention was based on an inquiry-based instruction in the unit of electricity and magnetism, targeting all NOS aspects including the tentative, subjective, and empirical.

The study involved 246 students from grade 8, 114 of them were assigned to the implicit group, and 132 were assigned to the explicit one. The intervention was designed in a way that both groups were given the same content knowledge tasks through four guided inquiry lessons spanning a duration of six weeks. However, the groups had distinct ways to develop knowledge about NOS. The explicit group was provided with self-regulatory science prompts and additional support and scaffolding in the form of checklists and questions to set goals and reflect on their own learning process. Conversely, the implicit group learned about NOS through inquiry activities, and were given extra questions related to content to make sure both groups had equal time participating in the intervention.

Initially, students in both groups had similar views of NOS. However, after the intervention, significant differences were obvious between the two groups, with the explicit group showing greater improvement in students’ views. Thus, suggesting that a reflective and explicit approach in the context of scientific inquiry lesson enables students to improve their views of the targeted NOS aspects.

In a separate context, Lau and Chan (2013) developed and evaluated three different interventions that intended to teach about NOS, particularly the theory laden aspect. Student participants from grade 9 were split into three groups. The first group was taught via modified lab inquiry where students investigated whether temperature would destroy the content of vitamin C in vegetables. Different from the extended and open-ended inquiry activities, the modified lab inquiry lessons were short and tweaked for students to experience and then reflect on the targeted NOS aspect. The second group was taught through a set of historical case studies which illustrated the theory laden aspect of science. Students in this group discussed historical episodes related to *H. Pylori* and Galileo's observations of the surface of the Moon. Lastly, the third group was taught by using a combination of the modified lab inquiry lessons followed by the historical case studies that were used with group two. It is important to mention that the targeted NOS aspect was explicitly taught in the three interventions.

Students' views on the theory laden aspect were assessed in a pre/post fashion using an open-ended questionnaire and interviews. Additionally, Students' lab reports were scrutinized for evidence that further revealed their understanding of the targeted NOS aspect. The data showed that both lab group and lab-history group showed considerable increase in students holding informed views of the targeted aspect. However, the history group did not show a significant change in the number of students holding informed views. The researchers concluded that a lab inquiry approach, whether combined with a historical case study or not, is far more effective compared to a historical case study on its own. The authors explain that a lab inquiry is a better context for students to experience a deeper reflection on NOS aspects, hence, has better chances of inducing mental conflicts to reconstruct a new informed understanding.

According to all the mentioned studies, framing inquiry activities with the content knowledge provides an effective context for teaching aspects of NOS. In the context of SI, students mimic the work of scientists and engage in student-centered activities that encourage them to construct their own knowledge. When students reflect on this engagement, they are prompted to critically think about how the scientific knowledge developed yielding a more sophisticated understanding of how science works.

History of Science. Instructions designed around the history of science involve incorporating historical episodes, discoveries, methodologies, and progression of scientific content. The context provides ample opportunities for teachers to address controversies, illustrate how scientific knowledge evolved over time, and highlight the social and cultural settings in which scientific knowledge was constructed (Jenkins, 2012). Thus, the context can be used as a pedagogical instrument to discuss and reflect on the epistemological dimension of science. According to Abd-El-Khalick and Lederman (2000) and Clough (2003), students can enhance their understanding of targeted NOS concepts when this instruction is coupled with scientific content in the context of historical episodes. Moreover, the literature provides compelling evidence to support the importance of using the context of HOS to enhance students' understanding of NOS. The following part of the report is a review of the literature highlighting the importance of HOS in pedagogical instruction to enhance NOS understanding.

Paraskevopoulou and Koliopoulos (2011) investigated the influence of a teaching intervention based on historical episodes on students' understanding of targeted aspects of NOS. The historical episode addressed the dispute between Millikan and Ehrenharft over the nature of the electric charge. The researchers noted that the subject of the episode provides a good context for teaching the targeted NOS aspects, which include the empirical nature of science, the distinction between observations and inferences, the role of imagination and creativity, and the subjective aspect of scientific knowledge.

Data was collected pre- and post-intervention in order to explore the changes in students’ views of the targeted aspects. The results resonated with a long line of research that concludes that students hold naïve perceptions of the targeted aspects of NOS. Nonetheless, post-intervention data showed significant improvement in students’ views of all targeted NOS aspects. Also, none of the students possessed naïve views of the aspects after the intervention.

In a separate study, Foad et al. (2015) explored the effect of using HOS contexts to teach elementary students targeted aspects of NOS. They further compared it to stand-alone inquiry approaches in an attempt to explore the optimum medium that will aid in enhancing adequate views of science. The students were split into two groups. The first group received explicit and reflective NOS instruction to teach targeted aspects via decontextualized (i.e. tricky tracks, fossil fragments, cubes) and inquiry activities. Whereas the history group, which is the second group, received explicit and reflective NOS instruction in HOS settings in addition to inquiry activities. The HOS was addressed in a set of lesson plans that included historical episodes of Archimedes’ solution to the Crown Problem in addition to Jabir ibn Hayyan episodes that tackle the concepts of chemical change and chemical reactions.

In order to answer the research questions posed, data was collected in a pre- and post-format using VNOSD questionnaires in addition to video recorded interviews to explore the effectiveness of the interventions. The researchers concluded that both the inquiry-only group and the HOS group were able to improve their understanding of the subjective, tentative, empirical and creative aspects of NOS, in addition to the distinction between observations and inferences. This conclusion deems HOS as an effective medium to teach NOS. Furthermore, students of the HOS group expressed interest in the learning experiences as they were able to relate to the scientists and the historical episodes.

On the other hand, Gandolfi (2020) developed a set of lesson plans to teach grade 8 students a set of NOS aspects in an attempt to broaden their understanding of the epistemological dimension of science. The researcher developed a set of teaching and learning plans (TLPs) in the context of history of science in order to integrate NOS concepts in addition to the content-specific learning objectives prescribed by the school curriculum. The TLPs addressed topics of medicine, evolution, magnetism, and earth's resources. Additionally, they were designed to teach various NOS aspects, including but not limited to tentativeness, scientific method, the social and cultural influence on construction of scientific knowledge, and the collaborative aspect of science. The intervention lasted for one year and included four TLPs. An explicit question-based and scaffolding-based approach was employed to help students elaborate on their own thinking and conversations when aspects of NOS are discussed.

The results showed significant improvement in students' views of NOS by the end of the year. It was evident that students' answers showed increased complexity on the NOS questionnaires establishing a stronger, inherent link between NOS and science content. Furthermore, the author concludes that the TLPs enhanced underexplored dimensions of science such as collaboration, cultural exchange, and political and financial aspects.

Overall, most studies evaluating the effectiveness of explicit NOS instruction in the context of HOS have shown positive results. Irwin (2000) emphasized the importance of incorporating HOS, as it gives the students an opportunity to experience the tentative and dynamic aspects of science. It also is an adequate context to introduce cultural, political, creative, personal/subjective aspects that shape the scientific endeavor (Gandolfi 2020, Khishfe 2023). Lastly, according to Eastwood (2012) HOS could positively impact students' attitudes towards science by boosting their motivation and their interest.

Socioscientific Issues. SSIs are controversial social problems that do not have a clear or a definite solution. They are open-ended issues with multiple solutions that are directly related to science (Eastwood et al., 2012). Sadler (2009) explains that students engaged with SSI are not only involved in the scientific knowledge related to the social issue, but they are also engaged in its economic, political, moral, ethical, and environmental implications that it may have on humans. Students learning in an SSI context practice a number of science process skills, including data analysis, argumentation, reasoning, and decision making (Sadler, 2011).

Previous studies on SSIs have proved that framing science lessons around social issues has the potential to promote argumentation skills (Khishfe, 2014), students' creativity (Lee & Erdogan, 2007), as well as students' motivation and attitude towards science (Lee & Erdogan, 2007; Yager et al., 2006). Research has also shown that using the context of SSI to teach content is at least equally effective as traditional learning environments (Yager et al., 2006). Furthermore, studies have shown that students' understanding of various NOS aspects can be improved when the lesson is designed in an explicit approach and contextualized in a frame of an SSI (Eastwood, 2012; Khishfe, 2014; Herman, 2018). The following part of the report will provide a brief review of the literature to highlight the importance of SSI contexts in teaching NOS.

Eastwood (2012) compared the effectiveness of explicit-reflective NOS instruction in two learning contexts. The researcher explored the change in students' NOS conceptions when NOS instruction is contextualized in SSI learning environment, as compared to when the instruction is framed in a science content-driven context. He further investigated qualitative differences in students' responses to NOS prompts in an attempt to reveal how each of the contexts transforms NOS understanding in unique ways.

Both the SSI-driven group and the content-driven group received explicit and reflective NOS instruction. The researchers created activities with an objective to teach the science content and particular NOS aspects, including the tentative, empirical, creative, and social aspect, in addition to the differences between theories and laws. For the SSI treatment, connections to NOS aspects were to be derived from controversial topics such as fluoridation of public water supplies, safety of marijuana, euthanasia, and stem cell research. On the other hand, for the content-driven treatment, the understanding of the targeted NOS aspects was to be developed via research related to the content of physiology and anatomy.

Students in both the SSI context and the content-driven contexts responded to the VNOS-C questionnaire pre- and post-treatment. Analysis of data from pre-test revealed that both groups possessed similar understanding of NOS aspects before the treatment. Data from post-test indicated that SSI contexts are as effective as content-driven contexts in transforming students' conception of targeted NOS aspects. However, from a conceptual perspective, fine scrutiny of qualitative data revealed that students in an SSI learning environment were more likely to provide examples of the social and cultural aspect of science, which, according to the authors, reflects a more sophisticated understanding of the related NOS aspects in comparison to the content-driven group. The results resonate with the conclusions reached by prior studies that suggest embedding NOS instruction in SSI as an effective strategy to teach nature of science (Khishfe & Lederman, 2006). Additionally, the authors argue that the study has pragmatic importance for teachers as it proves that designing SSI learning environments will not result in detracting students from learning the prescribed curriculum, including NOS.

In a different context, Khishfe (2014) examined the effect of explicit NOS and argumentation instruction on students' understanding of NOS and their argumentation skills in the context of SSI. A total of 121 grade 7 students participated and were randomly assigned to two treatment groups (Treatment I and II). For eight weeks, both groups were engaged in explicit NOS instruction, however, explicit instruction on argumentation was received in addition to NOS instruction in Treatment I only. The instructions were framed in the context of a SSI focusing on water usage and safety. The author justifies that the selected unit is relevant to students' real-life experiences as it addresses a scientific issue that is impacting their local communities. A set of NOS aspects were discussed in both treatments namely the subjective, tentative, and empirical aspects.

Students' views of the addressed NOS aspects were assessed pre and post treatments using two open ended questionnaires that focused on genetic modification of food and water fluoridation. Additionally, data was collected from interviews where students were asked to elaborate on their written responses on the questionnaires administered. Students' views of NOS were categorized into naïve, intermediate, and informed according to their consistency with the contemporary views of NOS. Aligned with prior research, most students had naïve understanding of the addressed NOS aspects prior to the explicit instruction in both treatments. On the other hand, both groups showed improvement in understanding of the NOS aspects after the explicit NOS treatments. However, only the treatment 1 group showed improvement in their argumentation skills. They were able to build connections between different argumentation components as a result of explicit argumentation instruction. Therefore, the results of the study are consistent with research findings that proved the efficacy of explicit NOS instruction in the context of a SSI.

Herman (2018) investigated the effectiveness of a place-based SSI instruction centered on the controversial environmental issue of re-introducing wolves to the Yellowstone area. In order to set the stage, the intervention started with watching documentaries about wolves, observing them in their natural habitat, and engaging with discussions with a field specialist who is involved in re-introducing the species back to the area. According to the author, such real-world experiences provided entry points to introduce a set of NOS aspects and further discuss the cultural, historical, and political underpinning of this environmental issue. The nature of science aspects discussed include the scientific method, the nature of scientific theories, the difference between observations and inferences, the cultural dimension of science, and the role of technology in our everyday life.

The Socioscientific and Ecological Engagement Dimension Survey II (SEEDSII) was employed to collect data pre and post the intervention. The survey included Likert scale items that gauged students understanding of the five NOS aspects mentioned, in addition to items that aim to explore students' intentions and compassion towards people and environment, and students' demographics. Data analysis has shown that students had naïve views of the epistemology of science, however, the post intervention data showed significant improvement students' NOS views, especially the ones related to nature of scientific theories, and the differences between observations and inferences. Additionally, the results showed improvement in students' compassion for nature and gains in pro-environmental intentions.

In conclusion, teaching NOS in the context of SSI can effectively develop students' understanding of its aspects, particularly those related to the social and the cultural dimensions. The SSI context provides an opportunity to explore the interaction between the individual and the society, and understand how they may mutually influence each other (Khishfe, 2023). According to Zeidler et. al (2002), engagement in SSI enables students to practice their critical thinking skills, search for evidence, consider different perspectives on societal issues, formulate opinions, and argue in support of them.

CHAPTER 3

METHODOLOGY

For the purpose of this report, we will adopt the consensus framework proposed by Lederman (2007). The framework adopted may not be universally accepted, and has been criticized by researchers, however, we believe that the framework can provide a foundational understanding to NOS and could be addressed in an increasing level of sophistication taking into consideration the developmental level of students. Furthermore, from a utilitarian point of view, and in reference to extensive research done on the matter, dimensions of the consensual framework are proved to be accessible to K-12 students and can be utilized by teachers to promote students understanding of NOS (Abd-El-Khalick, 2012).

Out of the seven aspects outlined, the scope of this report obliges us to focus on the (1) tentative, (2) subjective (3) empirical nature of scientific knowledge. Researchers believe that middle school students can access those particular aspects of NOS. Moreover, both Benchmarks for Science Literacy (AAA, 1993) and National Science Education Standards (NRC, 1996) have emphasized the importance of middle school students acquiring and understanding the targeted aspects in this report. Khishfe (2023) further argues that these aspects are significant predictors of students' argumentation skills, which are essential to science education. Lastly, the literature reviewed consistently examined these aspects to conclude that contextualized instruction, in all its forms, has a positive impact. Hence, underscoring the necessity to prioritize these three aspects in our report. The three aspects listed will be explained below.

Tentative aspect of scientific knowledge

The notion of tentativeness of knowledge is often unfamiliar to middle school students. We began our report with a short excerpt of a school discourse in a science classroom. The fact that the student believes that theories are absolute and cannot be falsified reflects a naïve understanding of the tentative nature of scientific knowledge. Attention to this particular aspect was driven by various factors. Firstly, it’s believed that an adequate understanding of this aspect can be achieved by middle school students (Lederman & O’Malley, 1990). Secondly, as reviewed before, results from earlier studies found that most students in K-12 schools have inadequate views of the tentative aspect of knowledge (Abd-El-Khalick & Boujaoude, 2003; Bell et al., 2011; Eastwood et al., 2012; Khishfe, 2020; Lederman & Lederman, 2014; Walker & Zeidler, 2007). According to Lederman and O’Malley (1990), understanding the tentative aspect of NOS helps in acknowledging the limitations that exist in ways of knowing, including the limitation related to instrumentation and observations. It also involves recognizing development in methods that construct knowledge such as re-interpretation of evidence in light of advances and breakthroughs. Furthermore, it helps us appreciate how our understanding of science has changed over time due to advances in methods and instruments (Lederman & O’Malley, 1990).

Subjective Aspect of Nature of Science

Another common belief about scientific knowledge is that it is characterized as subjective, or theory laden. The work of scientists is influenced by their prior knowledge and their own belief systems. A scientist’s unique mindset not only affects the way they conduct their experiments, but also the lens through which they interpret their data. Consequently, different conclusions may be reached by different scientists interpreting the same data. Chalmers (1999) elaborates on this aspect by explaining that different observers may have different perceptions of the same scene due to their background, personal experiences, and knowledge (Chalmers, 1999). Holmer and Singer (2019) argue that subjectivity diversifies interpretations of phenomena and may contribute to challenging existing paradigms and leading to groundbreaking discoveries. Understanding this aspect is important in our context, as it is in any context, to appreciate alternative explanations and unconventional methods (Holmer & Singer, 2019).

Empirical Aspect of Nature of Knowledge

Although philosophers of science and science educators agree that science involves human imagination and creativity, an essential aspect of science is its empirical nature and reliance on evidence (National Academies Press, 2013). The validity of scientific knowledge depends on the quality of this evidence. The emphasis on empirical evidence helps scientists reach a higher level of objectivity. Objectivity, in this sense, does not imply the existence of a single absolute truth, but rather that conclusions are based on empirical evidence independent of personal biases.

According to the National Research Council (2012), by understanding the empirical nature of science, students can become better critical consumers of knowledge. They learn to ask for evidence, evaluate it, and form their own conclusions on complex issues. Furthermore, Allchin (2011) explains that an improved understanding of the empirical nature of science will help students distinguish between what pertains to science and pseudo-science. In other words, it enables students to recognize what is valid scientific knowledge and what is not, based on the lack, or existence, of empirical evidence.

Developing Lesson Plans to Teach NOS

Like any curriculum development project, the process starts by identifying the end points, or the educational objectives that are intended by the lesson plans. The lesson plans are directed to grade 8 chemistry students studying in the Lebanese curriculum. They cover several units including Pure Substances, Chemical Reactions, and Acids and Bases. The following part of the report will draw on the recommendations and guidelines derived from the literature to develop the lesson plans of this report.

A wide array of research advocated for the use of explicit and reflective approaches to enhance students' understanding of NOS aspects. As discussed at length in previous parts of this report, explicit instruction entails intentionally targeting NOS as a cognitive learning outcome similar to theories and laws of science taught in class (Abd-El-Khalick & Akerson, 2004). Additionally, the reflective approach entails providing opportunities for students to analyze their activities and make connections to their experiences and the work of scientists to formulate conclusions about the epistemology of scientific knowledge (Abd-El-Khalick & Akerson, 2004; McComas et al., 2020). Table 1 maps the prompting questions that are used to incorporate a reflective and explicit approach in teaching the tentative, empirical, and subjective aspects of NOS.

For the SI-based lesson plans, in addition to providing a stage for an explicit and reflective discussion of NOS aspects, the literature recommends that the SI lesson be framed in a real-life context. The inquiry design should provide an authentic real-life context that mimics scientists' work. Based on the recommendations set by Lau and Chan (2013), the lesson plan designed in the context of an authentic real-life problem provides students with first-hand experience to delve deeper into their epistemological beliefs. Bell et al. (2003) also conclude that it is best to enhance students' understanding of NOS by creating tasks that help students connect classroom engagements to the scientific enterprise.

In addition to the real-life context, it is recommended for the lessons on scientific inquiry to utilize simple laboratory activities. Lederman and Lederman (2004) and Lau and Chan (2013) further recommend utilizing simple and commonly used laboratory activities, as opposed to complex and open inquiry, and modifying them to elucidate NOS aspects. This approach ensures that integrating NOS aspects does not require substantial effort, consume too much class time, or diverge the focus from scientific content. They further argue that the messiness of open inquiry may contribute to a loss of direction or focus to NOS aspects. Hence, they advocate for short, structured lab inquiries that could be specially modified to address a number of NOS aspects.

In addition to designing lesson plans in the context of SI, the literature provides recommendations for utilizing the history of science as a context to enhance the teaching of NOS aspects. Building on the findings from the literature, it is suggested to integrate historical cases in the curriculum. Irwin (2000) and Rudge and Howe (2009) argue for the importance of embedding science concepts within the historical development to highlight the evolution of knowledge and science thoughts. This is critical to illuminate the tentativeness of science as theories are falsified, and knowledge is developed. Additionally, this highlights the empirical aspect of NOS as observations and data support newly accepted interpretations and falsify outdated ones. This was evident in lesson plan three where the lesson starts by highlighting a historical concept of having four elements (fire, water, air and earth) and introduces the theory of phlogiston by George Stahl, providing a context for how people historically interpreted combustion. Additionally, lesson four explains the development of the atomic theory from Democritus's early concept of the atom to the modern quantum mechanical models.

Furthermore, it is recommended to conflate historical case studies with historical experiments. Fouad (2015) explains that recreating historical experiments provides first-hand experience on the empirical nature of scientific inquiry. The author concludes that combining inquiry within the historical context mimics the historical investigations and helps students appreciate the empirical and tentative nature of science. This was evident in lesson plan three where limestone was heated to test the phlogiston theory, mimicking historical experiments. This engages students in historical investigation methods to explain how the observations of this experiment may have led to naïve understanding of the phenomena. Further scientific experimentation in the lesson guides students to realize how the theory developed into a more sophisticated one as explained by Lavoisier. In the fourth lesson plan, historical experiments, such as Rutherford's gold foil experiment, prompt students to understand the importance of observation and collection data to challenge existing theories and lead to their development.

Lastly, a set of recommendations can also be derived to utilize socioscientific issues as a context to enhance aspects of NOS. Building on the findings from the literature, scaffolding and support are argued as a critical feature for SSI lessons addressing NOS. According to Walker and Zeidler (2007), this could be achieved by the use of guiding questions and structured prompts to help students think critically about NOS and SSI. The questions can guide students to consider the role of societal and ethical considerations in scientific debates, and the influence of science on governmental decisions.

In addition to scaffolding and support, promoting argumentation sets the stage for students to get engaged in debates related to the SSIs assists them to apply their NOS knowledge in the real-world contexts. According to Khishfe (2017), this engagement encourages students critically interpret different aspects of the social issues leading to a better understanding of the subjective and tentative NOS aspects.

Mapping the Lesson Plans to the Lebanese Curriculum

In order to meet the educational objectives and standards set by the Lebanese Ministry of Education (MOE), the lessons were designed to align with the scope and sequence of grade 8 in the intermediate level. The goal was to integrate the prescribed science content within the lesson plans to cover the material needed for national requirements, in addition to teaching the targeted NOS aspects. The scope and sequence determined by the MOE for grade 8 chemistry curriculum includes two themes: Classification and Constituents of Matter, and Chemical Reactions and Energy.

The first theme, Classification and Constituents of Matter, includes one unit: Pure Substances. Several lessons are covered in this unit, including Elements, compounds, Atoms, Molecules, Symbols and Formulas, and Allotropes. The second theme, Chemical Reactions and Energy, includes two units: Chemical Reactions and Acids and Bases. The lessons in the first unit include Chemical Equations, Types of Chemical Reactions, and Rate of Chemical Reactions. The second unit includes lessons on Acidic and Basic Solutions, the concept of PH, and Salts. For the scope of this report, we targeted lessons in both themes and covered all units.

The first lesson plan, designed in the context of the HOS, may be utilized by teachers in the first theme of Classification and Constituents of Matter, particularly in the unit of Pure Substances, for the lesson of Atoms. The students get engaged in a historical episode that highlights the development of scientific knowledge, leading to a more sophisticated understanding of the atom. The lesson addresses a few discoveries that contributed to our current understanding of the atom. Theories of the atomic model by John Dalton, Joseph J. Thompson, Ernest Rutherford, and Neils Bohr are discussed to appreciate the evolution of our understanding of the atomic model. The engagement with Rutherford’s gold foil experiment helps students falsify Thompson’s plum-pudding model to construct the basic understanding of a planetary model of an atom. The latter became the cornerstone of the discovery by Niels Bohr, who developed Rutherford’s planetary model to suggest that electrons occupy specific energy levels around the nucleus. Of course, the lesson may be used as an introduction to the electronic configuration of the first 20 elements of the periodic table.

The second lesson plan, also designed in the context of the HOS, may be utilized in the theme of Chemical Reactions and Energy, particularly in the unit on Chemical Reactions for the lesson of Chemical Equations to teach the objective of verifying and explaining the Law of Conservation of Matter. The lesson combines scientific inquiry with history of science, as students execute historical experiments to demonstrate how incomplete interpretation of results can lead to inaccurate conclusions that may support, for example, the Phlogiston theory. It further provides an opportunity to explore the historical changes in understanding the burning of substances, addressing the theoretical construct of Phlogiston and its falsification by Lavoisier, to construct the basic understanding of the Law of Conservation of matter. For this lesson, students should be able to distinguish between reactions occurring in an open system and a closed system. Additionally, they should be able to identify the type of reaction occurring, specifically synthesis and decomposition reactions. The lesson could be built upon introducing the concept of balancing equations in respect to the Law of Conservation of Matter.

The third lesson plan, designed in the context of SI, may be utilized by teachers in the theme of Chemical Reactions and Energy, specifically in the unit of Chemical Reactions, for the lesson of Rate of Reactions. It covers objectives related to understanding the rate of chemical reactions and the influence of temperature on these rates, in addition to NOS related objectives. Students at this stage should be able to define chemical change and identify evidence of a chemical reaction, including the formation of precipitate, fizzing and color change. They should also be able to interpret a chemical equation to identify reactants and products. Furthermore, students need to be familiar with molecular formulas and atomicity and be able to write a balanced equation. According to the scope and sequence shared by the MOE, those objectives fall under the theme of Chemical Reactions and Energy. Hence, the sensible flow would be to start with the lesson on Chemical Equations, then proceed to the lesson on Types of Chemical Reactions before covering the lesson on Rate of Chemical Reactions, where this lesson plan takes part.

The fourth lesson plan, also designed in the context of SI, is intended to be utilized in the first theme, which is Classification of matter, specifically in the unit of Pure Substances and the lesson on Elements. The students will learn about density as a criterion for purity, in addition to the targeted NOS aspects. When addressing elements as pure substances, the criteria taught to evaluate their purity and distinguish their identity include freezing point, boiling point, and density. It’s important to note that the arrangement of particles in a solid is a prerequisite to the designed lesson, and this objective is covered in grade 7. Hence, it would be useful to review how particles in a solid are arranged to successfully engage in the class demonstration involving two equally sized cubes of aluminum and copper. The task is further scaffolded for students to construct their understanding of density defined as the mass of a substance per unit volume, and to use the physical quantities of mass and volume to calculate the density of each plate.

The fifth lesson, designed in the context of SSI, pertains to the theme of Classification and Constituents of Matter. It is particularly tailored for students to explore how science may be utilized to mitigate the environmental impact of pollutant molecules such as carbon dioxide and sulfur dioxide, in addition to representing the particles in molecular models (e.g., ball and socket). According to the scope and sequence, combustion reactions and its environmental implications may be covered in grade 7; hence, the understanding of greenhouse effect and global warming, which is a prerequisite to this lesson plan should be revisited. Thus, it may be useful to introduce the issue through a class discussion or a YouTube video to familiarize students with scientific issues and set the stage for this lesson. Also, in order to address this possible gap, the students are instructed in the lesson plan to underline the terms that they perceive unfamiliar in the article and are asked to do their search to define it as they are engaged with the scientific content of the text.

The sixth and last lesson plan, also designed in the context of SSI, may be utilized in the theme of Chemical Reactions and Energy, specifically in the unit of Acids and Bases to highlight the environmental impact of Acid Rain. The lesson could be covered at the end of the unit, after students have explored the definitions of acids and bases and understood their properties and how they dissolve in water to form acidic and basic solutions. Additionally, understanding the consequences of acid rain on the environment is a prerequisite for this lesson. Lastly, it’s important for students to know the significance of methane as a greenhouse gas for successful engagement with the article. Hence, teachers should introduce the issue of methane through a class discussion to facilitate successful engagement and ensure clarity.

In summary, the lesson plans were articulated to align with the Lebanese Ministry of Education standards and the grade 8 chemistry syllabus, covering both themes and the units, ensuring exposure to NOS instruction in multiple contexts and various chemistry concepts. As we transition to the final section of this report, we will present our conclusion and offer recommendations that guide future directions to enhance the overall effectiveness of NOS instructional material.

Table 1

Explicit and Reflective Approach – Teaching the Tentative, Empirical, and Subjective Aspects of the NOS

Lesson plan	Tentative Nature of Science	Empirical Nature of Science	Subjective Nature of Science
Lesson Plan 1: History of Atom	The evolution of the atomic theory from the model of Democritus to Bohr's theory demonstrates the tentativeness of scientific knowledge and how its subject to change. **Prompting questions:** Explain how did Democritus's early model of the atom differed from the recent atomic theories, and what limitations does it demonstrate? Explain how Rutherford's gold foil experiment challenge previous models of the atom. In light of Rutherford's gold foil experiment and its impact on collective understanding of the atomic structure, explain how it illustrates the way scientists revise their theories with the emergence of new evidence.	The explanation of the Rutherford's gold foil experiment offers empirical evidence to falsify the prior models of the atom and contribute to reaching the contemporary models. **Prompting questions:** Describe Rutherford's model of the atom. What experimental evidence supported this model? Scientists use empirical evidence to reach their conclusions and construct knowledge. Explain how data is important in refuting knowledge. In light of Rutherford's gold foil experiment and its impact on collective understanding of the atomic structure, explain how it illustrates the way scientists revise their theories with the emergence of new evidence.	The lesson demonstrates how prior knowledge influence the production of knowledge. Students further explore how later models of the atomic theory build on earlier atomic models. **Prompting questions:** Describe Niels Bohr's model of the atom, compare it to earlier atomic models, and explain how it builds upon those previous models. To what extent did Niel Bohr's model of the atom rely upon previous models? Describe how scientists, in real life rely on prior discoveries done by other scientists?
Lesson Plan 2: Exploring Historical Theories of Burning: The Phlogiston Theory	The lesson demonstrates the paradigm shift from the phlogiston theory to the law of definite proportions, exemplifying how scientific theories may evolve with time. **Prompting questions:** Explain whether your data reject or confirm the theory of phlogiston? Verify how Lavoisier would use the data in this experiment to falsify the theory of phlogiston. Based on the results of the experiments, explain whether your prediction in question 1 was right or wrong. How do scientists adjust their hypothesis in light of new evidence?	Data was collected by finding the mass of limestone before and after heating to check the validity of the phlogiston theory. Students rely of more empirical evidence by to falsify phlogiston by tracing the change in mass as Mg is burned in a crucible. **Prompting questions:** Describe how George Stahl would use the data in this experiment to justify the theory of phlogiston. Explain whether your data reject or confirm the theory of phlogiston? Outline how Lavoisier would use the data in this experiment to falsify the theory of phlogiston. Do you think you need more evidence to reach a stronger conclusion?	The predictions formulated by students about the possible results of the limestone experiment are influenced by the historical science theories. Students were also asked to formulate predictions about the results of heating Mg in a crucible. Their predictions were influenced by prior findings of the limestone experiment. **Prompting questions:** Before the demonstration: Predict, based on phlogiston theory, what will happen to its mass? Think of the prediction you made before the demonstration. What made you formulate this prediction? On what basis did you formulate your prediction in the start of the lesson (Question 1)? Explain whether all the students have the same prediction and explanation. Deduce whether scientists, in real life, form the same predictions and explanations.

		Does the data validate or contradict the theory of phlogiston? How did you reach your conclusions? How do scientists reach their own conclusions? How do scientists adjust their hypothesis in light of new evidence?	
Lesson plan 3: Rate of Reaction	The students revisit their understanding after observing the brightness of glowing sticks in different temperatures, which may or may not be aligned with their initial prediction.	The investigation involved collecting qualitative and quantitative data that is interpreted in order to reach their conclusions regarding the effect of temperature on the rate of chemical reactions. The students are further prompted to evaluate their initial hypothesis.	Students formulate their hypothesis about glow sticks based on their personal reasoning influenced by past experiences and prior knowledge.
	Prompting questions: Show how the results of the activity supported or contradicted your initial prediction. After doing the experiment, did anyone find that their initial prediction was invalid? Did they change their mind? Explain. How does this process reflect the work of scientists? How do scientists change their minds?	**Prompting questions:** How did you reach your conclusion regarding the effect of temperature on rate of reaction? Show how the results of the activity supported or contradicted your initial prediction. Explain how you reached this conclusion? How do scientists reach their own conclusions?	**Prompting questions:** Think of the prediction you shared before the demonstration of the glowing sticks. Explain what made you formulate this prediction? Did all the students formulate the same prediction? Why do you think so? How did the students' predictions differ from each other? How do you think scientists' predictions and explanations vary in real-life scenarios?
Lesson plan 4: Criteria of Purity - Density	Students may initially assume that all metals are of the same mass and nature, especially after noticing that they have the same dimensions, color, and texture. This understanding is revisited after calculating the densities of each metal and comparing them with known values.	Data was collected by finding the mass and the volume of each metal strip using the necessary instruments. The data was further used to calculate the density of metals and to identify the nature of the material.	The discussions happening at the start of the class where each student is asked to identify whether the metals are nature and mass may reflect personal assumptions and classroom disagreement. This is built upon to highlight on the variations in scientists' predictions and explanations based on their prior experiences and interpretations.
	Prompting questions: Think back of the initial prediction in question (1), Does the demonstration validate or support your initial prediction? Did you (or any of your classmates) change your mind regarding the nature of each material? How do you think scientists change their minds? Based on the data produced, can you explain whether your initial prediction was right or wrong? How does this process reflect the work of scientists? How do scientists change their minds?	**Prompting questions:** Think back of the initial prediction in question (1), Does the demonstration validate or support your initial prediction? Did you (or any of your classmates) change your mind with respect to the nature of plates' materials? How? Explain how you reached your final conclusion regarding the material making up each plate. How do scientists reach their own conclusions? Based on the data produced, can you explain whether your initial prediction was right or wrong?	**Prompting questions:** Initial Prediction: Do you think that the metals are of the same mass? Are they made of the same material? Explain. Think of the prediction you made before finding the density of each plate. Explain what made you formulate this prediction? On what basis did you formulate your initial prediction in the start of the lesson? How did the students' predictions differ from each other? How do you think scientists' predictions and explanations vary in real-life scenarios? Did you (or any of your classmates) change your mind regarding the nature of each material? How do you think scientists change their minds?

Lesson Plan 5: Carbon dioxide gets stoned	The article demonstrates how methods for carbon capture evolve with new findings and evidence. The prompting questions further encourage the students to reflect on how knowledge and opinion may change with time in light of new findings and different perspectives, emphasizing that knowledge is always visited and revised.	The CarbFix project relies on experiments and observations to develop the technology. The article mentions how scientists conduct tests and collect data to evaluate their methods. The questions posed prompts students to utilize evidence in their claims and counter claims.	The questions prompt students to evaluate the strengths and limitations of CarbFix technology, discuss its impacts, consider conflicting opinions, and make a decision regarding the use of this technology.
	Prompting questions: Explain whether it's possible to revise your understanding in regard to utilizing CarbFix in the future. Given the new breakthrough that may result in having carbon dioxide captured with reduced cost, explain how researchers and government leaders may change their mind in relation to utilizing this technology.	**Prompting questions:** Scientific development may have social, economic, and/or environmental impact. Use the information in the article to discuss the impact of carbon capture on these categories. Support your answer with evidence. Would you recommend the use of carbon capture technology? Justify your answer and support it with evidence. Other scientists disagree with your recommendation above. Discuss how they could explain their position to convince you of their stance? On what basis did you formulate your position after reading the article? **Discuss** whether the government and the researchers would have the same position? Explain how scientists reach their conclusions.	**Prompting questions:** Would you recommend the use of carbon capture technology? Justify your answer and support it with evidence. Other scientists disagree with your recommendation above. Discuss how they could explain their position to convince you of their stance? Explain how scientists may have different opinions on the use of carbon capture even though they are all examining its various effects. Why do you think conflicting opinions might exist? On what basis did you formulate your position after reading the article? **Discuss** whether the government and the researchers would have the same position?
Lesson Plan 6: Acid Rain	New studies suggest that acid rain has direct influence on reducing methane emissions, thus, positively impacting the environment. Scientists are doubting whether acid rain is all bad. They are revising their understanding regarding the matter.	The universal negative perception of acid rain was challenged by newly emerging empirical evidence that concludes that the reduced methane emissions in wetlands is due to presence of sulfur.	The lesson is scaffolded to encourage students to consider how various scientific opinions and perspectives lead to different conclusions. While some researchers contend that acid rain has destructive effects on the environment, others, suggest that acid rain can have a beneficial role.
	Prompting questions: **Explain** whether it's possible to revise your understanding in regard to the issue of acid rain in the future. **Show**, from the article, why scientists may consider revising their knowledge on acid rain. After the emergence of evidence that concludes that acid rain is not all bad, did you change your mind about acid rain? **Explain**.	**Prompting questions:** **Explain** how scientists may have different opinions on the matter of acid rain even though they are all examining its various effects. **Show**, from the article, how scientists rely on observations and experimental results to reach conclusions.	**Prompting questions:** Other scientists disagree with your recommendation above. **Explain** how they could explain their position to convince you of their stance? **Explain** how scientists may have different opinions on the matter of acid rain even though they are all examining its various effects.

CHAPTER 4

CONCLUSION, RECOMMENDATIONS AND FUTURE DIRECTIONS

Research has concluded that the lack of effective instructional material to teach targeted NOS aspects is a major contributor to the inadequate understanding of the construct. This conclusion served as the primary motivation for our report. Our aim is to provide educators with effective lesson plans that facilitate NOS instruction, aligned with their taught curriculum, in an attempt to enhance students' understanding of the construct, and ultimately promote their scientific literacy.

Based on research findings in science education, the lesson plans were specifically designed to engage students in reflective, explicit, and contextualized instruction to maximize effectiveness. While some studies suggest that the decontextualized instruction may be equally effective, there is a compelling argument for teaching NOS in the context of scientific inquiry, history of science, and socioscientific issues. These vehicles provide an authentic experience for students to engage with and reflect upon NOS aspects, transform their understanding of the construct, and enhance underexplored dimensions of science such as collaboration, cultural exchange, and political and financial aspects. Additionally, these contextualized lesson plans are of practical importance to teachers as they are seamlessly entangled with existing curriculum content, ensuring an uninterrupted flow of instruction without compromising the pre-set educational goals.

As we conclude the report presented, it is important to turn our attention towards recommendations that could be beneficial for implementation. The lesson plans were designed based on extensive research and studies that incorporate an explicit reflective approach in a contextualized medium, a key condition for effective teaching. However, Clough (2006) argues that this might not be enough. He elaborates that teachers' inadequate understanding of NOS aspects may fail the students to transform their understanding and render the lesson plans non-effective. Hence, it is critical that science teachers have a solid understanding of NOS aspects. Research, as discussed above in the report, concludes that the majority of teachers hold a naïve understanding of the construct, thus, professional development workshops are crucial to transforming their understanding. Khishfe (2023) further concludes that training teachers to transform their NOS conception has a positive impact on students' understanding, thus, concurring with Clough (2006).

Secondly, based on the progressive nature of epistemic development, Khishfe (2023) argues that several models attempt to outline how individuals' views of epistemic knowledge may evolve through specific developmental stages before reaching a sophisticated view of NOS. Therefore, it is encouraged for NOS instruction to be introduced in an increasing level of complexity as instruction may progress from HOS, SI and lastly to SSI. The author suggests that introducing HOS in the early stages of NOS instruction can be highly effective. It offers students a chance to discuss and reflect on the work of scientists, their data collected, and evolution of knowledge. As mentioned before, integrating HOS instruction does not only contextualize with scientific content, but also serves to humanize the science and makes the subject less abstract (Khishfe, 2023).

Following HOS instruction, it is recommended to introduce SI. Lessons contextualized in SI provide the students with a stage to make their own predictions, collect their own data, actively constructing scientific knowledge, and reflecting on the process. Students mimic the work of scientists by collecting data, explaining it, and attempt to verify their own hypotheses. A process that requires thinking back, analyzing emerging data, build upon, and reflect on the whole process. Bell et al. (2003) explains that reflecting on the whole process requires an epistemic demand on the student to understand NOS and inquiry. In that sense, according to Khishfe (2023), this context will facilitate transforming students' understanding towards higher developmental levels.

Lastly, the SSI context should follow. Khishfe (2023) contends that instruction in the context of SSI engages students in higher-order thinking through the interplay of several elements of scientific literacy, including NOS, argumentation, decision making, science content, and scientific inquiry. Due to the possible cognitive overload, the author argues that it's best to place SSI context in later stages after introducing HOS and SI. The complexity introduced by SSI can be overwhelming and would require basic epistemological understanding, which is facilitated by earlier engagements in HOS and SI.

Furthermore, it's important to note that the scope of the report is limited to six lesson plans within the chemistry discipline in grade 8 and are designed to only teach three of the NOS aspects. To establish a comprehensive and systematic approach to teaching NOS, it is recommended to design lesson plans across all science disciplines and grade levels, incorporating all NOS aspects within the contexts of HOS, SI, and SSI. This broader approach would ensure consistent exposure to NOS and its aspects, facilitating a deeper and a more sophisticated understanding of a wider breadth of NOS among the students.

In conclusion, future research may explore several focus areas to optimize the teaching of NOS. Firstly, an empirical and comparative study may be significant to explore the effectiveness of different context (HOS, SI, SSI) in teaching NOS aspects, and conclude whether one context is more impactful compared to its counterparts. Additionally, an exploratory study to investigate the sequential approach that would yield a better NOS understanding should be conducted. Results of such explorations may provide a deeper insight into designing instructional approaches to teach NOS and may suggest alternative sequences for integrate the instruction to optimize students' understanding.

APPENDIX

BOOKLET:
TEACHING NATURE OF SCIENCE THROUGH THE DIFFERENT CONTEXTS: HISTORY OF SCIENCE, SCIENTIFIC INQUIRY, AND SOCIOSCIENTIFIC ISSUES

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21 July 2024

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INTRODUCTION

Scientific literacy has been a central goal for worldwide reform movements in science education (American Association for Advancement of Science, 1993; National Research Council, 2013). Philosophers and researchers have discussed several dimensions of scientific literacy, and agree that the epistemology of science, referred to as nature of science (NOS), is a crucial component. The National Research Council (NRC) (2013) emphasized the importance of teaching and learning NOS and identified it as one of the K-12 goals of science education. They further recognized its understanding as a condition for a student to achieve scientific literacy. Additionally, the American Association for Advancement of Science (AAAS) (1993) recommended giving science epistemology a prominent place in science classroom instruction, if scientific literacy was is to be one of its aims.

There exist general agreements over key aspects of NOS, rather than a general definition. According to Abd-El-Khalick et al. (1998), these aspects include science being (1) tentative as it is subject to change; (2) empirical as it's based on and/or derived from observation of the natural world; (3) subjective; (4) partially a result of human inference, imagination and creativity; and (5) socially and culturally embedded. The distinction between laws and theories, and between observations and inferences are further argued to be two additional key aspects of NOS.

Despite the widespread recommendations of having nature of science (NOS) understanding as an aim to science curricula in numerous studies and educational reforms, a review of the literature concludes that this goal has not been realized. Students, as it has been observed, lack an adequate understanding of the construct (Bell et al., 2011; Eastwood et al., 2012; Khishfe, 2020; Walker & Zeidler, 2007). Notably, this generalization is not disputed in Lebanon. BouJaoude (2002) further investigated elements of scientific literacy in the Lebanese curriculum to concluded that “science as a way of knowing”, i.e. scientific epistemology, was clearly mentioned in the broad objectives of the science curriculum. Nevertheless, the specific content and the requirements of the curriculum did not recommend the teaching and learning of NOS. Thus, concluding that the curriculum does not support students nor teachers in developing an accepted understanding of the construct. It is argued that the main factor contributing to the failure of achieving the desired understanding of NOS is the lack of effective NOS-focused instructional material (McComas et al.,2020).

Features to a Successful NOS Instruction

A significant body of research investigated various approaches to teach NOS. The effectiveness of an instructional approach was contributed to two major forms of instruction, namely the explicit-reflective and the contextualized. Abd-El-Khalick and Akerson (2004) explain that an explicit approach refers to educational practices in which the elements of NOS are distinctly articulated and clarified as a learning objective and a desired cognitive outcome. Whereas the “reflective” aspect of the instruction refers to creating opportunities for students to analyze the activities and establish connections between their experiences and the desired NOS aspects to make inferences about the epistemology of science. On the other hand, the term context refers to the settings in which the NOS instruction is delivered (McComas et al., 2020). A contextualized NOS instruction is one that is bound to science content (Clough, 2006). McComas et al. (2020) discussed three instructional contexts that are well-suited to promote students’ NOS understanding and they are outlined as follows: (1) history of science (HOS), (2) scientific inquiry (SI), and (3) socioscientific issues (SSI).

The Purpose of the Booklet

The purpose is to provide instructional material that will facilitate the teaching and learning of NOS. From this stand point, the aim is to provide grade 8 chemistry teachers with a booklet that comprises six detailed lessons plans that are aligned with the Lebanese curriculum, in addition to their respective student handouts that aim to teach NOS aspects in three different contexts, namely history of science, scientific inquiry, and socioscientific issues. The following will provide a brief overview on both the targeted NOS aspects and the contexts in which the lessons are designed.

OVERVIEW OF THE TARGETED NOS ASPECTS

Out of the seven aspects outlined, the scope of this report focuses on the (1) tentative, (2) subjective (3) empirical nature of scientific knowledge.

Tentative aspect of scientific knowledge

The notion of tentativeness of knowledge is often unfamiliar to middle school students. Attention to this particular aspect was driven by various factors. Firstly, it’s believed that an adequate understanding of this aspect can be achieved by middle school students (Lederman & O’Malley, 1990). Secondly, results from earlier studies found that most students in K-12 schools have inadequate views of the tentative aspect of knowledge (Abd-El-Khalick & Boujaoude, 2003; Bell et al., 2011; Eastwood et al., 2012; Khishfe, 2020; Lederman & Lederman, 2014; Walker & Zeidler, 2007). According to Lederman and O’Malley (1990), understanding the tentative aspect of NOS helps acknowledging the limitations that exist in ways of knowing, including the limitation that is pertained to instrumentation and observations. It also involves recognizing development in methods that construct knowledge such as re-interpretation of evidence in light of advances and breakthroughs. Furthermore, it helps us appreciate how our understanding of science has changed over time due to advances in methods and instruments (Lederman & O'Malley, 1990).

Subjective Aspect of Nature of Science

Another common belief of scientific knowledge is that it is characterized as subjective, or theory laden. The work of scientists is influenced by their prior knowledge and their own belief systems. A scientist's unique mindset does not only affect the way they conduct their experiments, but also the lens in which they interpret their data. Consequently, different conclusions may be reached by different scientists interpreting the same data. Chalmers (1999) elaborates on this aspect by explaining that different observers may have different perceptions of the same scene due to their background, personal experiences, and knowledge (Chalmers, 1999). Holmer and Singer (2019) argue that subjectivity diversifies interpretations of phenomena and may contribute to challenging existing paradigms and lead to groundbreaking discoveries. Understanding this aspect is important in our context, as it is in any context, to appreciate alternative explanations and unconventional methods (Holmer & Singer, 2019).

Empirical Aspect of Nature of Knowledge

Although philosophers of science and science educators agree that science involves human imagination and creativity, nevertheless, an essential aspect of science is its empirical nature and reliance on evidence (National Academies Press, 2013). The validity of scientific knowledge depends on the quality of this evidence. The emphasis on empirical evidence helps scientists reach a higher level of objectivity. Objectivity, in this sense, does not imply the existence of a single absolute truth, but rather that conclusions are based on empirical evidence independent of personal biases.

According to the National Research Council (2012), by understanding the empirical nature of science, students can become better critical consumers of knowledge. They learn to ask for evidence, evaluate it, and form their own conclusions on complex issues. Furthermore, Allchin (2011) explains that an improved understanding of the empirical nature of science will help student distinguish between what pertains to science and pseudo-science. In other words, it enables students to recognize what is valid scientific knowledge and what is not, based on the lack, or existence, of empirical evidence.

OVERVIEW OF CONTEXTS

This section of the booklet aims to provide a brief overview of the three frameworks of contextualization to teaching NOS. Those frameworks include scientific inquiry (SI), history of science (HOS), and soscioscientific issues (SSI).

History of Science

Instructions designed around the history of science involve incorporating historical episodes, discoveries, methodologies, and progression of scientific content. The context provides ample opportunities for teachers to address controversies, illustrate how scientific knowledge evolved over time, and highlight the social and cultural settings in which scientific knowledge was constructed (Jenkins, 2012). According to Abd-El-Khalick and Lederman (2000) and Clough (2003), students can enhance their understanding of targeted NOS concepts when its instruction is coupled with scientific content in the context of historical episodes. Moreover, literature provides compelling evidence to support using the context of HOS to enhance students’ understanding of NOS (Fouad et al., 2015; Gandolfi, 2020; Khishfe, 2022; Paraskevopoulou and Koliopoulos, 2011).

Scientific Inquiry

Numerous studies emphasize the importance of inquiry as a pedagogical approach to teaching NOS. In particular, Lederman (2013) highlights the significance of inquiry experiences, arguing that they provide valuable opportunities for students to reflect on various aspects of NOS. McComas et al. (2020) further elaborate that teaching and learning NOS through inquiry-based instructions can manifest in various forms. For instance, it could occur through project-based learning, where students are immersed in inquiry cycles to answer their research questions as commonly observed in science fair projects. Additionally, other forms might manifest in shorter laboratories activities tailored to teach specific scientific content and skills. Inquiry-based teaching and learning can also take place in short classroom activities that actively engage students in the learning process (McComas et al., 2020).

Socioscientific Issues

SSI are controversial social problems that do not have a clear or a definite solution. They are open-ended issues with multiple solutions that are directly related to science (Eastwood et al., 2012). Sadler (2009) explains that students engaged with SSI are not only involved in the scientific knowledge related to the social issue, but they are also engaged in its economic, political, moral, ethical, and environmental implications that it may have on humans. Students learning in an SSI context practice a number of science process skills, including data analysis, argumentation, reasoning, and decision making (Sadler, 2011).

The rest of the booklet will provide six detailed lesson plans in addition to student handouts to be used in class.

LESSON PLAN 1: TEACHING NATURE OF SCIENCE THROUGH HISTORY OF SCIENCE

Lesson Plan 1: History of the Atom

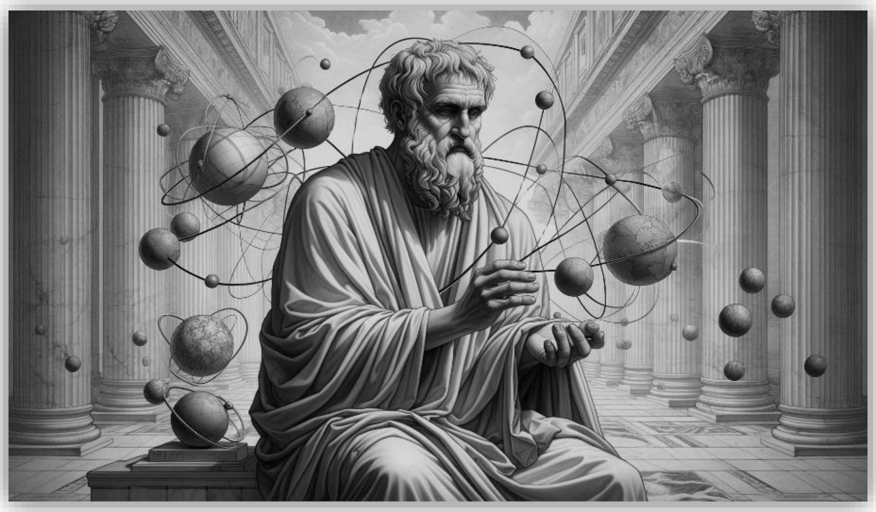
Prerequisites:

- Recognize that an element is the simplest form of matter that cannot be broken down by a chemical reaction.
- Define elements and compounds
- State how positive and negative charges interact

Learning objectives:

- Describe models of the structure of the atoms
- Explain the limitations of early atomic models and how subsequent models address these limitations.
- Explain the gold foil experiment
- Explain the empirical nature of scientific knowledge
- Describe the subjective nature of scientific knowledge
- Explain the tentative nature of scientific knowledge

Story of the Atom



(Helmold, 2024)

The majority of what we currently know has been discovered in the past 100 years or so, but the first model of an atom was established 400 BCE in ancient Greece by Democritus. According to Democritus's theory, matter can be divided into smaller and smaller fragments until it reaches a point where it could not be further fragmented. He named the smallest indivisible fragments "atomos", which means indestructible in Greek.

John Dalton, a British chemist, formulated an atomic theory to justify why chemical elements were combined in simple proportions. Dalton explained that elements are made of indivisible small particles called elements, and all elements are made of identical particles. He further stated that these elements bond together to form chemical compounds. Dalton's postulates were influenced by his observations when working with gases, which proved that the atomic theory was consistent with his experimental data.

Another British scientist, J. J. Thomson, discovered the presence of a particle smaller than the atom and called it an "electron". He proposed that there exists negatively charged electrons that are embedded in a sea of positive charge, analogous to a plum pudding. Hence, it was named the "plum pudding" model (Figure 1)

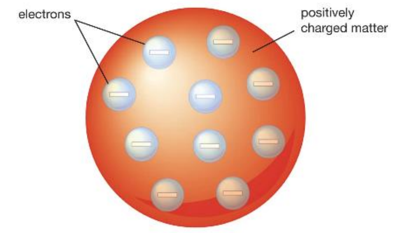


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Figure 1

In 1909, Ernest Rutherford, a scientist from New Zealand, reached a groundbreaking discovery that concluded that the atom is mostly empty space, disagreeing with Thomson and setting the stage for a shift in understanding what an atom entail. In his experiment, positive particles, known as alpha particles, were shot at a thin sheet of a gold foil (Figure 1). 99 % of the particles passed through the gold foil, and only small portion of them got deflected. The scientist explained that the deflection could be justified by the repulsion force exerted by a strong positive charge located in the center of the gold atoms.

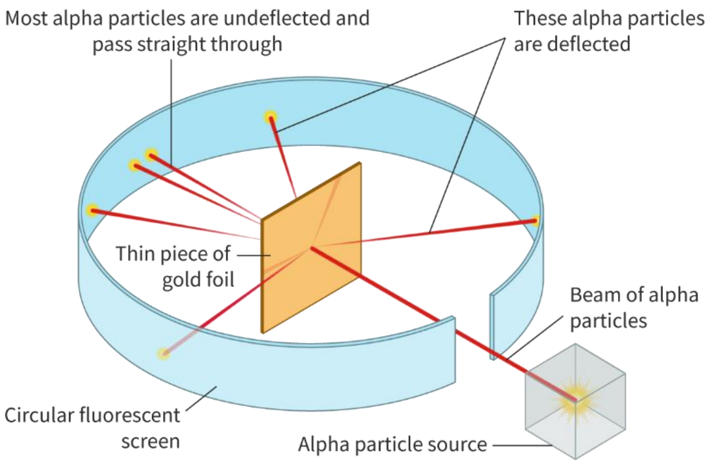


Figure 1: Thin piece of gold foil bombarded by alpha particles; note the deflection as some alpha particles collide with the positively charged nucleus.

In 1914, the model of the atom was further developed by Danish physicist Niels Bohr. Bohr proposed that electrons can only exist in certain fixed energy levels and that they can transition between these energy levels by absorbing or emitting exact amounts of energy.

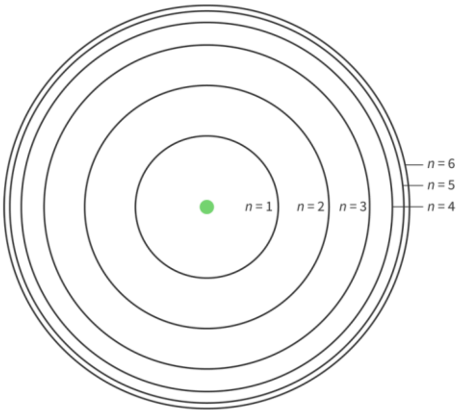


Figure 2: The main energy levels in an atom from n = 1 to n = 6

Questions: THINK – PAIR – WRITE - SHARE

1- **Explain** how did Democritus's early model of the atom differ from the recent atomic theories, and what limitations does it demonstrate?
2- **Describe** Rutherford's model of the atom. What experimental evidence supported this model?
3- **Explain** how Rutherford's gold foil experiment challenge previous models of the atom.
4- **Describe** Niels Bohr's model of the atom, **compare** it to earlier atomic models, and **explain** how it builds upon those previous models.

Reflective and Explicit Discussion

This is a teacher guided whole class discussion. The role of the teacher is to facilitate the discussion and to prompt the students to elaborate more in their explanations. The teacher needs to challenge the students to improve their understanding of nature of science. It is not recommended that the teacher provides answers, but steer the discussion to reach desired understanding.

5- **To what extent** did Niel Bohr’s model of the atom rely upon previous models? **Describe** how scientists, in real life rely on prior discoveries done by other scientists?
(Subjective aspect of nature of nature of science)

6- Scientists use empirical evidence to reach their conclusions and construct knowledge. **Explain** how data is important in refuting knowledge.
(Empirical aspect of nature of science)

7- In light of Rutherford’s gold foil experiment and its impact on collective understanding of the atomic structure, **explain** how it illustrates the way scientists revise their theories with the emergence of new evidence.
(Empirical and tentative nature of science)

8- **Describe** how one can generalize from this discussion how science works?
(Special focus should be put on the tentative, subjective and empirical nature of science)

LESSON PLAN 2: TEACHING NATURE OF SCIENCE THROUGH HISTORY OF SCIENCE

Lesson Plan 2: Exploring Historical Theories of Burning: The Phlogiston Theory

Pre-requisites:

- Distinguishing the difference between a reaction happening in an open system and a closed system
- Writing word equations
- Atomicity
- Interpret a chemical equation
- Identify the type of reaction

Learning Objective:

- Verify the law of conservation of mass
- Explain the empirical aspect of nature of science
- Explain the subjective aspect of nature of science.
- Explain the tentative aspect of nature of science.

The ancient Greeks thought everything was made from fire, water, air and earth

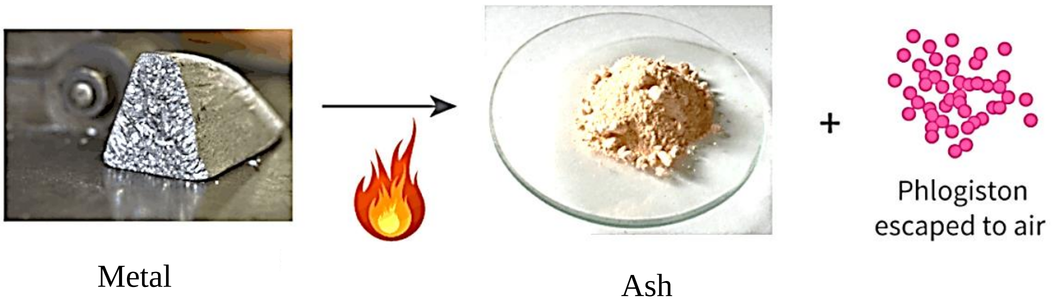
(Andrewgenn, 2014)

During the 1600's, scientists thought that air was one single substance, and that burning depended on air. Robert Boyle (1627-1691) was heating a tin piece of metal in his laboratory. He placed the piece of metal inside a sealed container. Boyle noticed that the mass of the metal increased when it was heated. He thought that the fire that is supposed to escape got stuck between the particles of the metal.

(Tingle, 2014)

A German scientist named George Stahl (1659 – 1734) established the idea of Phlogiston theory (derived from Greek phlox = flame). His theory explains that when a substance burns, it turns into two substances: ash and phlogiston. Ash is left behind on earth surface, and phlogiston escapes into the air. Hence, the substance will get lighter when its burned. During that time, the theory had the power to explain a number of observations, thus, it was accepted by the scientific community (Change, 2024).

(*Georg Ernst Stahl* | *German Chemist and Physician* | *Britannica*, n.d.)



(Credits: Tomekbudujedomek, Getty Images (bottom left); Source: "Oxid olovnatý" by Ondřej Mangl is in the public domain (bottom right))

The following idea encompassed Stahl's phlogiston's theory:

- Phlogiston is found in all combustible substances
- Substances burn better when they contain more phlogiston
- The combustion process releases phlogiston to air, which appears in the form of fire.
- Ores and metals may not produce flames of fire as phlogiston is released slowly and gradually.
- The ash left behind after heating is called calx
- Calx is less dense than the metal because it has lost phlogiston

The theory had the power to explain a number of observations, particularly reactions that were economically significant at the time. The below will demonstrate the power of phlogiston in explaining the change in the mass of heated limestone:

Demonstration: Heating Limestone

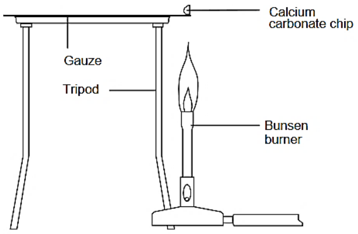
Smelting is the process of extracting a metal from its ore by using heat.

Calcium carbonate, known as limestone, is heated using a Bunsen Burner as shown in the diagram below.

1. Before the demonstration: Predict, based on phlogiston theory, what will happen to its mass?

Demonstration:

Your teacher will demonstrate the experiment below:



Procedure:

- Use 2 limestone chips and weigh them. Record the measurement.
- Place the limestones over the gauze surface and heat them using the Bunsen Burner for 10 minutes.
- Use the tongues to remove the chips and reweight them. Record the measurement.

2. Record your observations:

   Mass of the sample before heating: …………………/g

   Mass of the sample after heating: ………………../g

3. Explain whether the results confirm or reject the theory of phlogiston.
4. Explain whether you need more evidence to reach a stronger conclusion.
5. Describe how George Stahl would use the data in this experiment to justify the theory of phlogiston.

   (Empirical nature of science)

6. Think of the prediction you made before the demonstration. What made you formulate this prediction?

   (Subjective nature of science)

7. Calcium carbonate breaks down into calcium oxide and carbon dioxide.

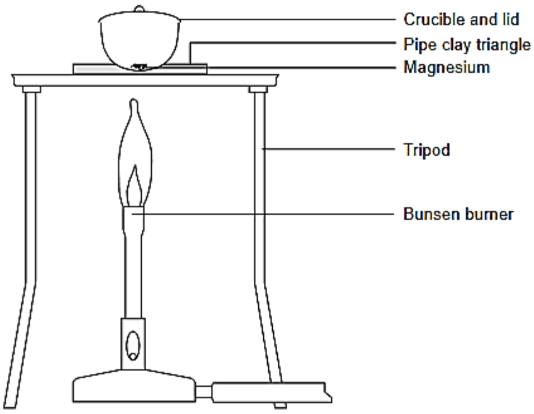
   i. Write the word equation for the chemical reaction
   ii. The balanced chemical reaction is outlined below:

$$CaCO_3 \rightarrow CO_2\,(g) + CaO$$

   The symbol (g) implies that CO_2 is in the gaseous state. Where does this gas go? How do you think this may affect the measured mass after burning?

Antoine Lavoisier (1743-1794) was a French chemist, who was widely regarded as the father of modern chemistry. Lavoisier made significant contribution to chemistry when he challenged the theory of phlogiston to falsify it. He investigated burning of metals, and thought that their data proves that the theory is not quite right. Working with Sulfur, Lavoisier found its mass increases. However, according to phlogiston theory, the mass is supposed to decrease. Something was wrong here!

Experiment: Falsifying Phlogiston (Students work in groups of 4)



Experimental Set

Materials needed:

- Mg ribbon sanded to release the oxide layer.
- Bunsen Burner
- Crucible
- E-balance
- Clay triangle
- Crucible tongues

Procedure:

- Weigh the mass of the empty crucible (with its lid) and record the results below.
- Place the Mg ribbon inside the empty crucible (lid on) and weigh them on the e-balance. Record the results.
- Place the crucible (lid on) on the top of clay triangle above the Bunsen Burner. Heat for 15 minutes. Remove the lid occasionally and carefully to prevent any solid ash from escaping.
- After 15 minutes, transfer the heated crucible to the bench.
- Weigh the crucible after heating. Record the results.

Carefully record your results:

- Mass of the crucible + lid: ……………………………….. /g
- Mass of crucible + lid + sample: ……………………………….. /g

	Appearance of Sample	Mass of Sample /g
Start		
End		
		Difference in mass /g =

Post Experiment Questions: THINK – PAIR – WRITE - SHARE

8. How did the mass of the sample change after heating?
9. When magnesium is heated, it reacts with oxygen to form magnesium oxide. Write the word equation of the reaction.

10. The balanced equation is: $2Mg\ (s) + O_2\ (g) \rightarrow 2MgO\ (s)$
    Based on the chemical reaction, explain why the mass of the Mg sample change in mass.
11. **Explain** whether your data reject or confirm the theory of phlogiston?
    (Tentative nature of science)
12. **Outline** how Lavoisier would use the data in this experiment to falsify the theory of phlogiston.

    (Empirical nature of science)

13. The law of conservation of matter states that “nothing is created; nothing is destroyed; all is transformed, which means that there is an equal amount of matter before and after the chemical reaction”. Using the law, and in reference to reactions happening in open systems, explain the below:

- A sample of calcium carbonate decreases in mass when its heated by a Bunsen burner.
- A sample of magnesium increases in mass when it burns in air.

Reflective and Explicit Discussion

This is a teacher guided whole class discussion. The role of the teacher is to facilitate the discussion and to prompt the students to elaborate more in their explanations. The teacher needs to challenge the students to improve their understanding of nature of science. It is not recommended that the teacher provides answers, but steer the discussion to reach desired understanding.

1- On what basis did you formulate your prediction in the start of the lesson (Question 1)? Explain whether all the students have the same prediction and explanation. Deduce whether scientists, in real life, form the same predictions and explanations.
(Subjective aspect of nature of nature of science)

2- Does the data validate or contradict the theory of phlogiston? How did you reach your conclusions? How do scientists reach their own conclusions?
(Empirical aspect of nature of science)

3- Reflect on the outcome of the experiment:

   a. Based on the results of the experiments, explain whether your prediction in question 1 was write or wrong.
   b. Describe how this resembles the work of scientists in the real world.
   c. How do scientists adjust their hypothesis in light of new evidences?

(Empirical and tentative nature of science)

4- How does this discussion show how science works?
(Special focus should be put on the tentative, subjective and empirical nature of science)

Reference:

Tingle, M. (2014). *The logic of phlogiston*. RSC Education. https://edu.rsc.org/feature/the-logic-of-phlogiston/2000126.article

LESSON PLAN 3: TEACHING NATURE OF SCIENCE THROUGH SCIENTIFIC INQUIRY

Lesson Plan 3: Factors Affecting the Rate of Reaction
Purpose: Investigating temperature as a factor influencing the rate of reaction.

Prerequisites:

- Define chemical reactions, reactants, and products.
- Define rate of reaction
- Identify slow reactions and fast reactions

Learning Objective:

- Identify temperature as a factor that influences the rate of chemical reaction
- Explain the effect of temperature on the rate of a chemical reaction
- Explain the empirical aspect of nature of science
- Explain the subjective aspect of nature of science.
- Explain the tentative aspect of nature of science.

Pre-demonstration Questions:
Students can work in pairs to answer and discuss the questions. Ask them to Think – Pair – Write – Share

1- How would you start a glowing stick?
2- What do you think you should do for the glowing stick to last longer?
3- What do you think you should do for the glowing stick to glow brighter?

4- **Initial prediction:** Which of the two glow sticks will glow stronger? Longer? Provide a reasoning for your prediction

Make sure you ask the students to share their predictions and have them written on the board. We will refer to them later.

Material for Demonstration:

- Ice water in an insulated cup
- Hot water in an insulated cup
- 2 glow sticks

Demonstration: The teacher places one glow stick in hot-water cup, and another in the cold-water cup for at least two minutes.

The teacher removes the sticks and bends them to start the reaction.

The teacher leads the post-demonstration discussion and records the answers on the board.
Explain that when students bend the stick to start it, a small container is breaking inside the stick, and chemicals are in contact to react.

Post Demo questions: Think – Pair –Write - Share

5- How does placing a stick in cold temperature affect its glow?
6- Why does the stick in a cold environment last longer while the stick in hot water glows brighter?

Investigation: Does the temperature of reacting substances affect the speed of reaction?

Material for each pair:

Water
Calcium Chloride
Baking Soda
Graduated Cylinder
Teaspoon
2 clear plastic containers
4 smaller clear plastic cups
2 small clear containers
Hot water (40 – 50 ^oC)
Ice water (0 – 5 ^oC)
Masking tape
Pen
stopwatch

Procedure:

Preparing the baking soda solution:
- Use the masking tape and a pen to mark 2 baking soda solutions, and 2 calcium chloride solutions.
- Use the graduate cylinder to add 20 mL of water in one of the baking soda cups.
- Add 2g of baking soda to the cup containing water and shake to dissolve.
- Pour half the baking soda solution into the other empty baking soda cup.

Preparing the calcium chloride solution:
- Use the graduated cylinder to add 20 mL of water into one of the calcium chloride cups.
- Add 2g of calcium chloride to the cup containing water and shake to dissolve.
- Pour half the calcium chloride solution into the other empty calcium chloride cup

Altering the temperature of the solutions

- Pour hot water into one of the containers, and cold water into the second. Make sure that the water is only filling ¼ of the container. Those will be the hot and cold-water baths.
- Place a one baking soda and one calcium chloride solution in the hot water bath, and place the other two solutions in the cold-water bath. Keep them for 30 seconds.

Add the solutions

- At the same time, add the cold solutions to each other, and the hot solutions to each other. Use the stopwatch to observe and record the time for a visible precipitate to form.

Record your findings below:

Condition	**Quantitative data (Time /sec)**	**Qualitative data** *Fizzing (Longer/Shorter)* *Brightness (more/less intense)*
Reactants at HIGHER temperature	**What is the time needed for the precipitate to become visible?** _______________	
Reactants at LOWER temperature	**What is the time needed for the precipitate to become visible?** _______________	

Questions:

7- Based on the result, how does the temperature of the reactants affect the rate of reaction?
8- Based on your results, explain your qualitative data.
9- Based on your results, explain how do the findings of the experiment help you understand the “glowing stick” demonstration.

When the students are done with the experiment, the teacher needs to openly discuss the results of the experiment. In case discrepancies are evident in students’ explanations, they need to further discuss in-between them and try to convince each other. The role of the teacher is to facilitate the discussion occurring in the classroom.

Open-ended Questions:

Students work in pairs to answer the below questions in writing.

10- Think of the prediction you shared before the demonstration of the glowing sticks. Explain what made you formulate this prediction?
    (Subjective nature of science)
11- Did all the students formulate the same prediction? Why do you think so?
    (Importance of prior knowledge and subjective nature of science)
12- How did you reach your conclusion regarding the effect of temperature on rate of reaction?
    (Empirical nature of science)
13- Show how the results of the activity supported or contradicted your initial prediction.
    (Empirical and tentative nature of science)

Reflective and Explicit Discussion

This is a teacher guided whole class discussion. The role of the teacher is to facilitate the discussion and to prompt the students to elaborate more in their explanations. The teacher needs to challenge the students to improve their understanding of nature of science. It is not recommended that the teacher provides answers, but steer the discussion to reach desired understanding.

1- On what basis did you formulate your prediction in the start of the lesson? How did the students' predictions differ from each other? How do you think scientists' predictions and explanations vary in real-life scenarios?

    (Subjective aspect of NOS – Students tried to hypothesize based on prior knowledge)

2- Explain how you reached your conclusion? How do scientists reach their own conclusions?

    (This is based on the quantitative and qualitative findings: Aspect of empirical nature of science)

3- Reflect on the outcome of the experiment:
    a. After doing the experiment, did anyone find that their initial prediction was invalid? Did they change their mind? Explain.
    b. How does this process reflect the work of scientists? How do scientists change their minds?
    (Empirical and tentative nature of science)

4- How does this discussion show how science works?
    (Special focus should be put on the tentative, subjective and empirical nature of science)

LESSON PLAN 4: TEACHING NATURE OF SCIENCE THROUGH SCIENTIFIC INQUIRY

Lesson Plan 4: Criteria of Purity – Density
Purpose: Investigating the nature of different metals by determining their densities.

Prerequisites:

- Differentiate between pure substance and mixtures
- Describe the physical properties of solids
- Describe the arrangement of atoms in a metallic piece of solid.

Learning Objective:

- Understand that density is a characteristic property of a substance
- Recognize that objects of same volume but different mass have different densities.
- Calculate density
- Explain the empirical aspect of nature of science
- Explain the subjective aspect of nature of science.
- Explain the tentative aspect of nature of science.

Students will observe how a copper and aluminum cube have the same volume but different masses, and try to explain this observation on the molecular level. Students are given plates of different metals of the same color and volume, and are asked to identify the nature of each plate.

Materials for the demonstration:

- Copper and aluminum cubes/plates of same volume
- Digital Balance

Material for the investigation per group:

- 4 pure metal plates of the same volume: Aluminum, Zinc, Nickle, Iron
- Digital Balance

Pre-demonstration Engagement:

Introduce the material for each group. Students should be able to see and touch the different metal plates. It will be clear to students that the plates are of the same size, volume, color, and texture.

1- Initial Prediction: Do you think that the metals are of the same mass? Are they made of the same material? Explain.
(Students answer individually on their handouts)

2- Use the e-balance to measure the mass of each plate. Record your findings below:
(Students answer individually on their handouts)

Metal Plate	Mass (in g)
Plate 1	
Plate 2	
Plate 3	
Plate 4	

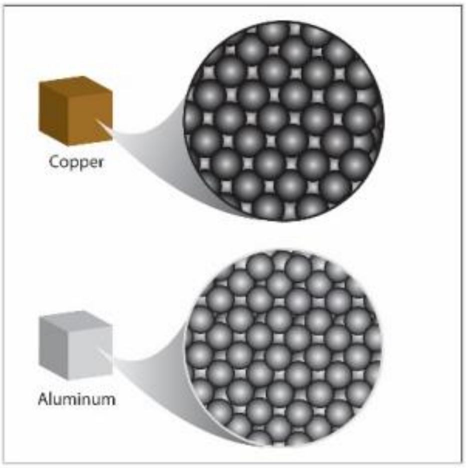
Table 1

3- How can objects of the same size and shape have different masses?
(Students answer individually on their handouts)

Demonstration:

The teacher places a copper plate and an Aluminum plate on a balance to demonstrate that a copper plate is heavier than the aluminum. Both cubes are not hollowed. The copper cube is made purely of copper, and the Aluminum is purely made of aluminum.

Look at the figure on the right showing copper and aluminum cubes and their atoms. The copper atoms appear to be slightly bigger in size than the Aluminum atoms. Hence, there appears to be fewer copper atoms in the copper cube than aluminum atoms in the aluminum cube.



Post-demonstration Engagement: Use the THINK – PAIR – WRITE – SHARE routine to answer the questions:

4- If there are fewer copper atoms in the cube, why does the copper cube weigh more?

(Explain to the students that the particles in metals are arranged in the same way. Copper atoms are a little bigger than the aluminum atoms, this means that fewer atoms

exist in the copper plate, however, the individual copper atoms are heavier. So even though there might be less atoms of copper, however, their mass makes the plate heavier)

(Explain the concept of density as related to how an object is heavy in comparison to its volume. The mass and the volume of the object determines its density. Objects of same volume will be heavier when they have a higher density – Each substance has its own characteristic density because of the mass and size of its atoms.)

5- Think back of the initial prediction in question (1), Does the demonstration validate or support your initial prediction?

Investigation: Your goal is to use density to identify the metallic nature of each of the plates.

Procedure:

a) Note the mass of each plate from the data on table 1.
b) Calculate the density of each plate using the formula d=m/v
c) Record your values in the table below.

Hints: Keep the "material" column empty. We will refer to it later.

Plate	Mass (g)	Volume (cm^3)	Density (g/cm^3)	Material
1		18		
2		18		
3		18		
4		18		

Table 2

Questions: THINK – PAIR - WRITE

Refer to the given values in table 3 below to:

i- **Use** the information given in table 3 to identify the material that makes up each plate.
ii- Write the name of each material in table 2.

Material	Approximate Density
Aluminum	2.9
Brass	8.8
Copper	9.3
Steel	8.2

Zinc	7.1
Nickle	8.9
Iron	7.8

Table 3

iii- Even though the plates have the same color, size and shape, they are made of different materials. Explain.

iv- If a metal has a higher density, what can you hypothesize about the mass of the atoms making it up?

Open-ended Questions: Students answer in writing: THINK – PAIR - WRITE

1- Think of the prediction you made before finding the mass of each plate. **Explain** what made you formulate this prediction?

2- Did you (or any of your classmates) change your mind with respect to the nature of plates' materials? How?

(Subjective and tentative – you tried to explain based on prior knowledge)

3- **Explain** how you reached your conclusion regarding the nature of each metallic plate.
(Empirical nature of science)

4- After finishing this lab session and answering all the questions, can you **describe** how science works and how scientists construct their knowledge?

(Discussion should have special emphasis on subjectivity, empirical, and tentative nature of science.)

Reflective and Explicit Discussion

This is a teacher guided whole class discussion. The role of the teacher is to facilitate the discussion and to prompt the students to elaborate more in their explanations. The teacher needs to challenge the students to improve their understanding of nature of science. It is not recommended that the teacher provides answers, but steer the discussion to reach desired understanding.

1- On what basis did you formulate your initial prediction in the start of the lesson? How did the students' predictions differ from each other? How do you think scientists' predictions and explanations vary in real-life scenarios?

   (Subjective aspect of nature of science)

2- Did you (or any of your classmates) change your mind regarding the nature of each material? How do you think scientists change their minds?

   (Subjective and tentative aspect of nature of science: The students changed their predictions based on new understanding and knowledge)

3- **Explain** how you reached your final conclusion regarding the material making up each plate. How do scientists reach their own conclusions?
   (Empirical nature of science)

4- Reflecting on the outcome of the experiment:
   a. **Based on the data produced**, can you explain whether your initial prediction was right or wrong?
   b. How does this process reflect the work of scientists? How do scientists change their minds?
   (Empirical and tentative nature of science)

5- How does this discussion show how science works?
   (Special focus should be put on the tentative, subjective and empirical nature of science)

LESSON PLAN 5: TEACHING NATURE OF SCIENCE THROUGH SOCIOSCIENTIFIC ISSUES

Lesson Plan 5: Carbon dioxide gets stoned

Prerequisites:

- Distinguish between atoms and molecules.
- Recognize the representation of elements using their symbols
- Determine the elements and the number of atoms making up a molecule
- Define renewable energy
- Understand greenhouse effect and global warming

Learning objective:
- Use the ball and stick model to represent carbon dioxide and hydrogen sulfide
- Evaluate the strength and limitations of carbon capture
- Explain the tentative nature of scientific knowledge
- Explain the empirical nature of scientific knowledge
- Explain the subjective nature of scientific knowledge

Material:

- Digital device, if applicable. If not, the teacher can provide printed copies of the article.
- A3 papers, if needed.
- Ball and stick kit

This article puts chemistry concepts within the context of emerging carbon capture technologies. Students often encounter issues related to carbon dioxide emissions and climate change in news and media. This article could be utilized to enhance teaching combustion of hydrocarbons, carbon cycle, and molecules.

The full article could be accessed and downloaded through this link: Carbon dioxide gets stoned

The article is also added to the next page to be accessed and utilized by offline users. The students shall be asked to arrange themselves in groups of 3-4 to work on the following task.

GRASP can be used for an authentic student engagement.

Goal: Your goal is to actively get engaged with a text that addresses carbon capture technology, evaluate its strength and limitations, understand its impact, and discuss different scientific views. You will be working in groups to search, discuss, and present your findings.

Role: You are a member of a team of environmental scientists. You will present your analysis and recommendations to your classmates.

Audience: The audience will be your classmates, your teacher, and your debate club, if applicable. You will present your finding and interact with the audience to lead the discussion.

Situation: As a team, you have been assigned to investigate CarbFix technology presented in this article. It involves capturing CO_2 from air and injecting it in basalt rocks to reduce its concentration in the atmosphere, mitigating global warming.

Product: Your product could be any of the following:

- A3 mind map
- Power Point presentation
- Poster (Canvas)

The product must include:

1- An introduction for carbon capture including its definition
2- Assembling and present the ball and stick model of carbon dioxide, sulfuric acid, and calcium carbonate.
3- Definition of terms that you find unfamiliar. You can use search engines to reach the definitions.
4- Summary of strength and limitations of CarbFix
5- Scientific development may have social, economic, and/or environmental impact. Use the information in the article to discuss the impact of carbon capture on these categories. Support your answer with evidence.
6- Would you recommend the use of carbon capture technology? Justify your answer and support it with evidence.
7- Other scientists disagree with your recommendation above. Discuss how could they explain their position to convince you of their stance?
8- Explain how scientists may have different opinions on the use of carbon capture even though they are all examining at its various effects. Why do you think conflicting opinions might exist?
9- Explain whether it’s possible to revise your understanding in regards to utilizing CarbFix in the future.

End of task

Reflective and Explicit Discussion

This is a teacher guided whole class discussion. The role of the teacher is to facilitate the discussion and to prompt the students to elaborate more in their explanations. The teacher needs to challenge the students to improve their understanding of nature of science. It is not recommended that the teacher provides answers, but steer the discussion to reach desired understanding.

1- On what basis did you formulate your position after reading the article? **Discuss** whether the government and the researchers would have the same position? *(Subjective aspect of nature of nature of science)*

2- Explain how scientists reach their conclusions.

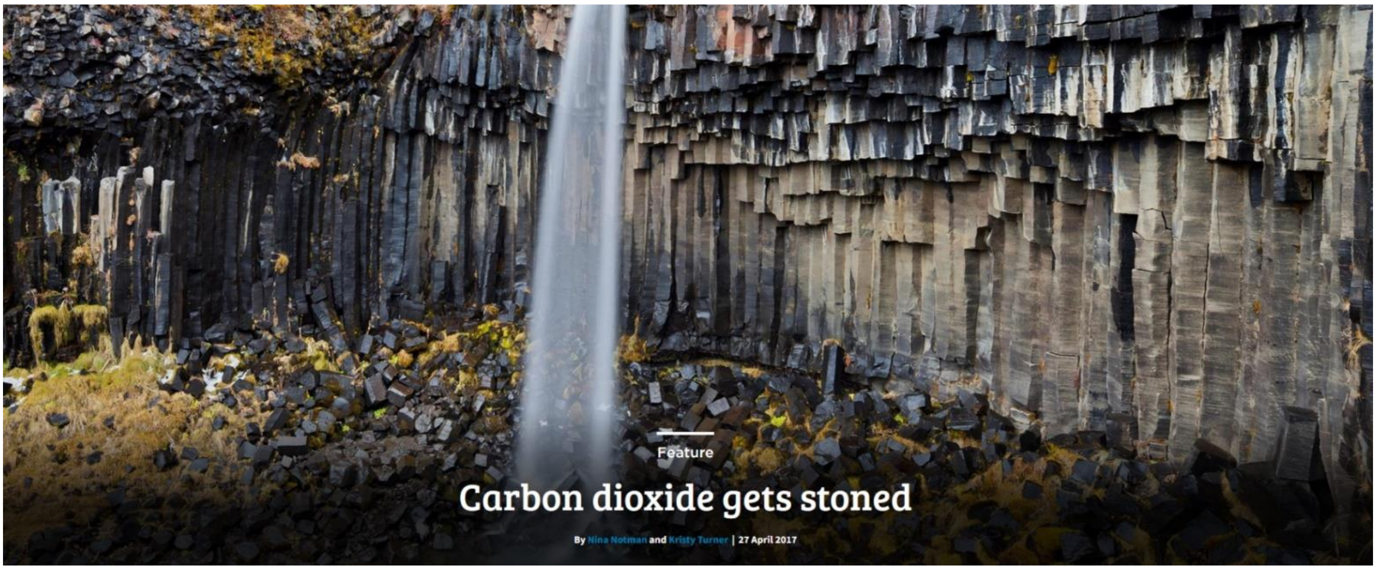
   (Empirical aspect of nature of science)

3- The technology of carbon fixing developed over time, particularly in finding alternative ways to inject carbon dioxide into basalt with a reduce cost. Given the new breakthrough that may result in having carbon dioxide captured with reduced cost, explain how researchers and government leaders may change their mind in relation to utilizing this technology.

   (Empirical and tentative nature of science)

4- Describe how one can generalize from this discussion how science works?

   (Special focus should be put on the tentative, subjective and empirical nature of science)



Carbon dioxide gets stoned

Education in Chemistry
May 2017
rsc.li/EiC317-carbon-capture

Nina Notman meets the teams exploring the potential of locking Earth's excess carbon dioxide away for millions of years by turning it into rock

Iceland is widely touted as a leader in green energy, generating 100% of its electricity from renewable sources. It might come as a surprise, then, to hear that this sparsely populated country has a huge carbon dioxide emissions problem. This is because although Iceland's two electricity sources – hydropower and geothermal – are promoted as being clean, they do still cause the emission of significant amounts of carbon dioxide and other gases.

A secondary issue is that Iceland produces a lot of electricity for industrial purposes, explains Eric Oelkers, professor of geochemistry at University College London. The availability of copious amounts of electricity at consistently low prices has attracted the global aluminum production industry to the country. The extraction of aluminum from aluminum ore is a very energy-hungry process. 'Iceland imports aluminum ore, smelts it and then exports the aluminum again,' Eric says.

Volcano power

Eric has been overseeing a novel initiative to reduce emissions at the country's largest geothermal power plant. Hellisheidi produces electricity and hot water from the Hengill central volcano, with a capacity of 300 MW of electricity and 120 MW thermal.

The initiative, CarbFix, is a carbon capture and storage (CCS) project with a twist. Conventionally, the carbon dioxide captured using CCS is stored underground in depleted oil and gas reservoirs or other locations where it is unlikely to leak back out again. However, Iceland's volcanic nature means it doesn't have any nicely sealed underground reservoirs suitable for long-term gas storage. Eric's team therefore needed to develop an alternative approach.

Instead, the team is injecting carbon dioxide captured at Hellisheidi into basalt, a reactive rock rich in divalent cations such as calcium and iron. Here it reacts to form the carbonate mineral calcite (CaCO3). This locks the gas away for millions of years in an environmentally benign manor. 'The only solution there was for Iceland was to get the carbon dioxide to react with basalts to make carbonated rocks,' Eric explains. 'Once the carbon dioxide is mineralized it stays there forever: the average age of a carbonate rock in the crust is 200 million years old.'

Source: © Johann Helgason/Shutterstock
Hellisheidi geothermal power plant in Iceland

The project started in 2006, and has been through many design and testing stages. In 2016, the team reported in Science surprising findings from its final pilot plant study at Hellisheidi. The carbon dioxide they had injected into the basalt had reacted to form rock in less than a year; it had been predicted this process would take many years.
But while the technology development has proceeded near perfectly, it hasn't been a smooth ride getting this far. 'There have been some twists and turns in the story,' Eric says. 'Over the years it became clear that there is no financial model to make carbon capture and storage work. Many of these projects globally started shutting down. It costs money to do and if no government was going to force people to do it, nobody would.'

The Icelandic government, however, was happy to fund the removal of a second hazardous gas from Hellisheidi's flue gases: hydrogen sulfide (H2S). Unlike carbon dioxide, hydrogen sulfide has an immediate impact on the local population. 'It smells of rotten eggs,' Eric explains. 'Because of increasing energy production, the levels of hydrogen sulfide were beginning to get too high in some parts of Iceland. What we did is expand the capture and storage of carbon dioxide to capture and store, simultaneously, hydrogen sulfide and carbon dioxide.' Hydrogen sulfide, when injected into basalt rocks, rapidly forms pyrite (FeS2), also known as fool's gold. The hydrogen sulfide part of this project is called SulFix.

Since 2014, the CarbFix-SulFix project has been operating on a commercial scale. 'About two-thirds of the gases produced by the plant are currently injected and this will be upscaled to 100% within about a year,' Eric says. Without the capture technology, Hellisheidi emits about 40,000 tonnes of carbon dioxide and 12,000 tonnes of hydrogen sulfide each year. To put this in context, this is about 5% of the emissions that would come from a similarly-sized coal-powered plant.

The technology

The first generation of the CarbFix technology involved separating the carbon dioxide from the flue gases, dissolving it in water and then injecting it into basalt rock. Water reacts with carbon dioxide to form carbonic acid (H2CO3), which plays an important role in the mineralization process. In the final pilot study reported in Science, the gas from the plant was also combined with extra carbon dioxide brought in from elsewhere, including some spiked with heavy carbon (carbon-13) to aid monitoring of the mineralization process. (Samples are still routinely taken from wells to monitor the pH and geochemistry at the injection site.)

The request to capture and inject hydrogen sulfide from the flue gases as well allowed the process to be simplified. 'What we do now is take the exhaust gas from the power plant and put it through something called a sparger, which is a fancy name for a shower,' says Eric. 'Raining water on the exhaust causes the carbon dioxide and hydrogen sulfide to dissolve. We then take this pressurized water and inject it directly into the ground. It's very simple.' The process has been shown to work with both fresh and seawater.

Energy is the only major cost associated with the project once the system has been installed. 'Energy is used in the inner pressurization of system used to dissolve the carbon dioxide and hydrogen sulfide in the gas,' Eric explains. But the amount of energy required is far less than for conventional CCS units that inject the gas into disused oil wells and the like. It has been estimated the CarbFix-SulFix process will use up approximately 0.2% for the power produced at Hellisheidi. This compares well to the 3 to 10% typically reported for conventional CCS units at coal- and gas-fired power plants. This equals significant cost savings. 'The cost of doing this is approximately $25 a tonne, compared to in the order of $60 to $120 a tonne with conventional technology,' says Eric.

The success of this mineralization process opens the doors for the CarbFix-SulFix setup to be replicated at other power plants. ‘Basalts are very abundant,’ says Eric, both on land and under the sea. ‘Pretty much all the ocean floors are basalts, which is an advantage because people don’t seem to want carbon dioxide injected underneath their homes,’ he adds. Ultimately, however, Eric believes that politics will determine whether the technology is eventually used elsewhere.

Meanwhile, in January 2017, his team started to develop their technology to capture carbon dioxide directly from the air. ‘Less than half of the carbon dioxide that goes into the atmosphere comes from power plants. More than half comes from cars, jet planes, etc. We're going to have to air capture eventually,’ he says. Again, this technology would be suitable for any site near basalts and with lots of water available. ‘We’re teaming up with an air capture company to do this on the coastline of Iceland.’

Over the pond

Eric’s team are not the only ones looking at the potential of capturing carbon dioxide and turning it into rock. The CarbFix project is, however, by far the most advanced. To date, only one other team – the Big Sky Carbon Sequestration Partnership at Montana State University in the US – has taken the testing of this technology out of the lab and into the field.

In 2013, the Big Sky team, together with the not-for-profit organization Battelle, injected around 1000 tons of carbon dioxide into basalt rock at a site in Washington State. ‘This was a moderate scale pilot where we injected purchased carbon dioxide, we didn’t capture it. It was to prove the principle,’ explains the project’s director Lee Spangler. ‘The purpose of the pilot was to field test injection of carbon dioxide into basalts, and see in situ what the chemical reactivity was, and how quickly that carbon dioxide would start turning into rock.’

‘The major difference between what we were doing and what has been done in Iceland is that the Icelandic team dissolve the carbon dioxide in water or brine before it is injected, whereas at the pilot we performed, it was injected as pure carbon dioxide gas,’ Lee says.

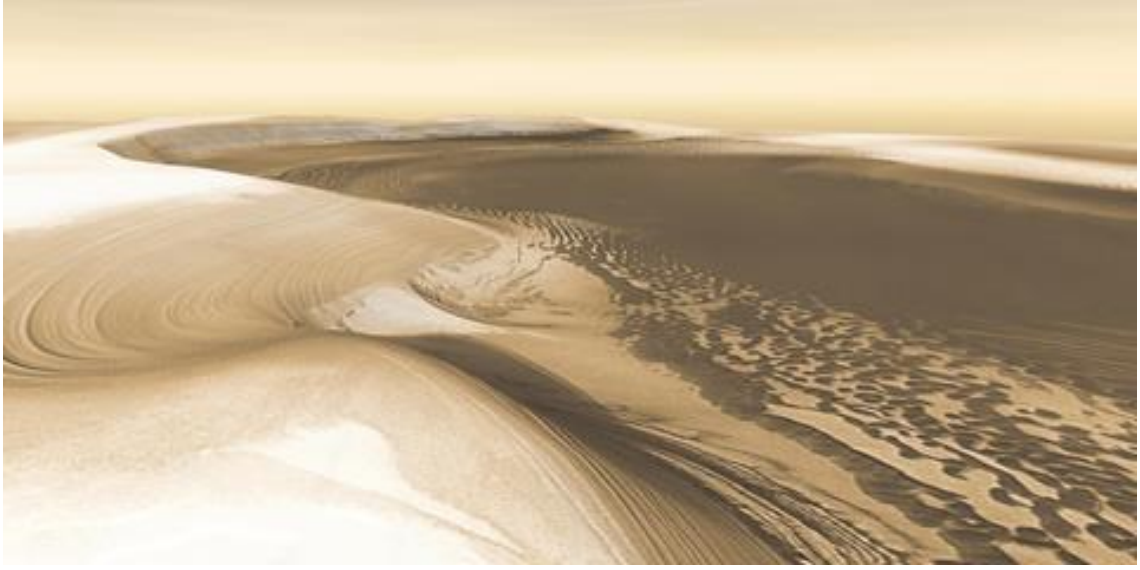
There is some brine or water in basalt rock naturally, but the absence of the step to pre-dissolve the carbon dioxide could change the chemistry of the mineralization process. ‘Carbon dioxide dissolved in water becomes carbonic acid, and the reactivity of that can be different to injecting free phase carbon dioxide,’ says Lee. ‘Battelle laboratory tests showed it would still rapidly convert to minerals, but we wanted to check it in situ. The advantage of injecting it as pure carbon dioxide is that you don’t have to go through that step of dissolving it in water.’ Removing the pressurized water step will obviously reduce costs.

The pilot was a success, and sampling and monitoring at the site continued for a further 18 months following the injection process. The funding for this project has now ended and Lee’s team have turned their attention to conventional CCS. The so-called Kevin

Dome Project is testing the potential of storing gaseous carbon dioxide long-term at an underground site in Montana.

How Mars turned to rock

Although the concept of capturing carbon dioxide from flue gases, or the air, and turning it into rock may sound a little out-there, it is a process that occurs naturally on Earth – albeit very slowly. Researchers in Glasgow also believe the same process may have been responsible for the dramatic thinning of the atmosphere on Mars a few billion years ago. The thin layer of gas that surrounds this planet contains around 95% carbon dioxide. Evidence, such as dried up river beds on its surface, suggests around 4 billion years ago the atmosphere was much thicker – thick enough to support life in fact.



Source: © NASA/JPL/Arizona State University, R. Luk
Mars has bright polar caps of ice that are easily visible from telescopes on Earth. A seasonal cover of carbon-dioxide ice and snow is observed to advance and retreat over the poles during the Martian year.

It is not known for sure what happened to all that gas, but one theory is some of the carbon dioxide was sucked into rocks and mineralized. In 2013, scientists at the University of Glasgow reported evidence to support this claim; they found veins of carbonate minerals in a Martian meteorite thought to have landed on Earth around 3000 years ago.

‘In the laboratory we are now using high-pressure, high-temperature experiments to recreate approximately the Martian environment at that time,’ explains PhD student Adrienne Macartney. ‘The idea is to try to chemically and visually replicate the kind of carbonates we see in the Martian meteorites, with the general notion being if you’re chemically and physically replicating them, then perhaps the conditions you’ve used are similar to those on very early Mars.’

The similarities between these two research fields is obvious. ‘Mars is an example where we know a very similar process to CarbFix’s has happened naturally. But it’s happened on a very large, planetary scale. The areas we are looking at are hundreds of thousands of kilometres of potential reaction site, instead of just like couple of square kilometres in Iceland,’ Adrienne says.

Studying the natural process on Mars might also help us predict the potential impacts of CCS. ‘The work to understand the extent to which it potentially has affected the atmosphere on Mars might be helpful to help quantify the effects which this kind of technique might have on Earth. At the moment, there’s really not much dialogue between carbonate researchers on Mars and Earth.’

This is something Adrienne hopes to address. ‘We have an enormous amount of expertise in a lot of the same problems, so we may just find there’s a lot more efficiency in solving the terrestrial climate issues if we worked together.’

Article by Nina Notman, a science writer based near Baltimore, US.

Further reading

- The CarbFix project: bit.ly/carbfix-project
- Basalt pilot project: bit.ly/big-sky-basalt
- University of Glasgow, planetary science and astrobiology research group: solarsystemrocks.org/current-research

LESSON PLAN 6: TEACHING NATURE OF SCIENCE THROUGH SOCIOSCIENTIFIC ISSUES

Lesson Plan 6: Acid rain not all bad
Prerequisites:

- Define acids and bases.
- Describe the chemical reactions that lead to the formation of acid rain.
- Explain the environmental impact of acid rain
- Outline the role of methane in contributing to greenhouse effect.

Learning Objectives:

- Evaluate the environmental impact of acid rain
- Explain the tentative nature of scientific knowledge
- Explain the empirical nature of scientific knowledge
- Explain the subjective nature of scientific knowledge

Acid rain not all bad

(Bowen, 2019)

Acid rain can benefit the environment by blocking one of the most powerful greenhouse gases, scientists said yesterday.

Research led by Vincent Gauci, from the Open University's department of earth sciences, shows that the Sulphur in acid rain dramatically reduces the natural production of methane, responsible for an estimated 22% of the greenhouse effect that is causing global warming.

Acid rain, produced by industrial emissions of Sulphur dioxide, destroys forests and kills fish and other aquatic animals.

Over the past 20 years European industry has become much cleaner, and the EU is committed to further emission reductions by 2010.

But the study, published in the journal Proceedings of the National Academy of Sciences, suggests it might be unwise to halt acid rain completely.

Dr Gauci's research showed that other bacteria which thrive on Sulphur compete with the methane-makers. Their numbers are so boosted by acid rain that they can significantly reduce methane generation from wetlands. Dr Gauci's team carried out experimental research on wetlands in Morayshire, Scotland, to test the effect of Sulphur depositions on methane emissions. The data were then combined with a computer model from the American space agency, Nasa, to provide a global picture.

It showed that the effect of acid rain from 1960 to 2030 could reduce methane emissions to pre-industrial levels.

"The effect more than compensates for the increase in methane emission that would be expected as wetlands become warmer," said Dr Gauci. "In effect, acid rain is acting like a lid on the largest methane source. "

https://www.theguardian.com/science/2004/aug/03/sciencenews.research

Reporter, G. S. (2018, February 14). Acid rain not all bad. *The Guardian*.

https://www.theguardian.com/science/2004/aug/03/sciencenews.research

Read the text well before answering the questions below: THINK – PAIR – WRITE - SHARE

1- There are a number of ways to address the issue of acid rain:

   A. We may not take any action to address the matter, because, after all, acid rain appears to be beneficial to the environment.

   B. Reduce the production of pollutant gases by controlling the combustion of fossil fuels. This will mean that we will be using more public transportation rather than using our private cars, and the government will impose more taxes on importing cars.

   C. Reduce the production of pollutant gases by treating our fuel before consumption. This is an expensive process and the citizens will be paying for this in an indirect way.

   a. Which suggestion would you recommend?
   b. Justify your answer.

2- Other scientists disagree with your recommendation above. Discuss how could they explain their position to convince you of their stance?

3- After the emergence of evidence that concludes that acid rain is not all bad, did you change your mind about acid rain? Explain.

4- Discuss how scientists may have different opinions on the matter of acid rain even though they are all examining at its various effects.

5- Based on your knowledge of the adverse effect of Acid Rain, and in reference to the article you just read, determine whether the governments need to take serious measures to stop Acid Rain.

6- Explain whether it's possible to revise your understanding in regards to the issue of acid rain in the future.

7- **Show**, from the article, why scientists may consider revising their knowledge on acid rain.

8- **Show**, from the article, how scientists rely on observations and experimental results to reach conclusions.

Reflective and Explicit Discussion

This is a teacher guided whole class discussion. The role of the teacher is to facilitate the discussion and to prompt the students to elaborate more in their explanations. The teacher needs to challenge the students to improve their understanding of nature of science. It is not recommended that the teacher provides answers, but steer the discussion to reach desired understanding.

1- **Explain** the rationale behind the position you formulated in question 1.
(Subjective aspect of nature of nature of science)

2- **Explain** how scientists reach their conclusions.
(Empirical aspect of nature of science)

3- Given the new evidence that acid rain is not entirely harmful, describe how your views on acid rain have changed. Additionally, **explain** how this process reflects the way scientists revise their understanding based on new findings.
(Empirical and tentative nature of science)

4- **Describe** how one can generalize from this discussion how science works?
(Special focus should be put on the tentative, subjective and empirical nature of science)

STUDENTS’ HANDOUTS

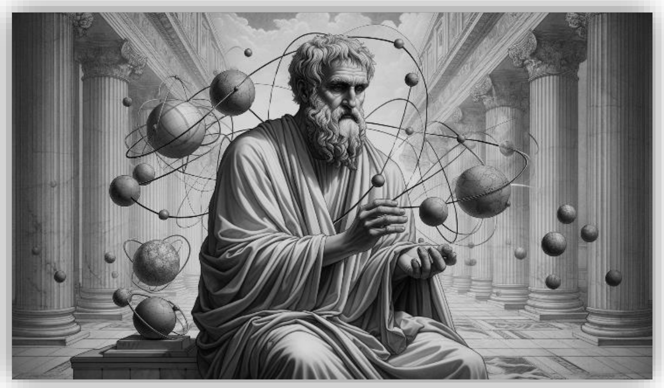
Name_________________________

Date__________________________

Handout 1: History of the Atom

Teaching Nature of Science Through History of Science
History of the Atom

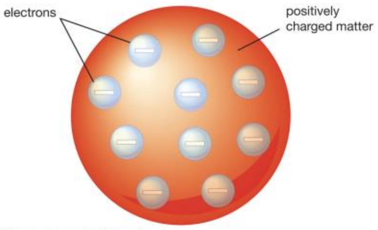
The majority of what we currently know has been discovered in the past 100 years or so, but the first model of an atom was established 400 BCE in ancient Greece by Democritus. According to Democritus’s theory, matter can be divided into smaller and smaller fragments until it reaches a point where it could not be further fragmented. He named the smallest indivisible fragments “atomos”, which means indestructible in Greek.



(Helmold, 2024)

John Dalton, a British chemist, formulated an atomic theory to justify why chemical elements were combined in simple proportions. Dalton explained that elements are made of indivisible small particles called elements, and all elements are made of identical particles. He further stated that these elements bond together to form chemical compounds. Dalton’s postulates were influenced by his observations when working with gases, which proved that the atomic theory was consistent with his experimental data.

Another British scientist, J. J. Thomson, discovered the presence of a particle smaller than the atom and called it an “electron”. He proposed that there exists negatively charged electrons that are embedded in a sea of positive charge, analogous to a plum pudding. Hence, it was named the “plum pudding” model (Figure 1)



© 2012 Encyclopædia Britannica, Inc.

Figure 1

In 1909, Ernest Rutherford, a scientist from New Zealand, reached a groundbreaking discovery that concluded that the atom is mostly empty space, disagreeing with Thomson and setting the stage for a shift in understanding what an atom entail. In his experiment, positive particles, known as alpha particles, were shot at a thin sheet of a gold foil (Figure 1). 99 % of the particles passed through the gold foil, and only small portion of them got deflected. The scientist explained that the deflection could be justified by the repulsion force exerted by a strong positive charge located in the center of the gold atoms.

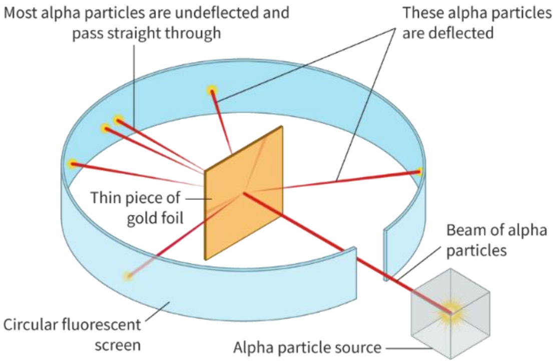


Figure 1: Thin piece of gold foil bombarded by alpha particles; note the deflection as some alpha particles collide with the positively charged nucleus.

In 1914, the model of the atom was further developed by Danish physicist Niels Bohr. Bohr proposed that electrons can only exist in certain fixed energy levels and that they can transition between these energy levels by absorbing or emitting exact amounts of energy.

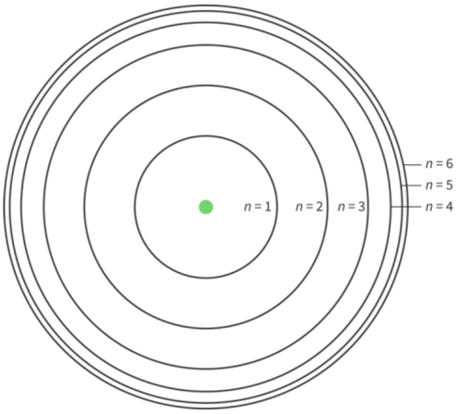


Figure 2: The main energy levels in an atom from n = 1 to n = 6

Questions: THINK – PAIR – WRITE - SHARE

1- **Explain** how did Democritus's early model of the atom differ from the recent atomic theories, and what limitations does it demonstrate?

2- **Describe** Rutherford’s model of the atom. What experimental evidence supported this model?

3- **Explain** how Rutherford's gold foil experiment challenge previous models of the atom.

4- **Describe** Niels Bohr's model of the atom. **Specify** how relies upon previous models of the atom?

5- **Compare** Bohr's model to the previous ones.

Reflective and Explicit Discussion

1- **To what extent** did Niel Bohr's model of the atom rely upon previous models? **Describe** how scientists, in real life rely on prior discoveries done by other scientists?

2- Scientists use empirical evidence to reach their conclusions and construct knowledge. **Explain** how data is important in refuting knowledge.

3- In light of Rutherford's gold foil experiment and its impact on collective understanding of the atomic structure, **explain** how it illustrates the way scientists revise their theories with the emergence of new evidence.

4- **Describe** how one can generalize from this discussion how science works?

Name_________________________
Date__________________________

Handout 2: Exploring Historical Theories of Burning: The Phlogiston Theory

Teaching Nature of Science Through History of Science
Exploring Historical Theories of Burning: The Phlogiston Theory

The ancient Greeks thought everything was made from fire, water, air and earth.

(Andrewgenn, 2014)

During the 1600’s, scientists thought that air was one single substance, and that burning depended on air. Robert Boyle (1627-1691) was heating a tin piece of metal in his laboratory. He placed the piece of metal inside a sealed container. Boyle noticed that the mass of the metal increased when it was heated. He thought that the fire that is supposed to escape got stuck between the particles of the metal.

(Tingle, 2014)

A German scientist named George Stahl (1659 – 1734) established the idea of Phlogiston theory (derived from Greek phlox = flame). His theory explains that when a substance burns, it turns into two substances: ash and phlogiston. Ash is left behind on earth surface, and phlogiston escapes into the air. Hence, the substance will get lighter when its burned. During that time, the theory had the power to explain a number of observations, thus, it was accepted by the scientific community (Change, 2024).

(*Georg Ernst Stahl | German Chemist and Physician | Britannica*, n.d.)

(Credits: Tomekbudujedomek, Getty Images (bottom left); Source: "Oxid olovnatý" by Ondřej Mangl is in the public domain (bottom right))

The following ideas encompassed Stahl's phlogiston's theory:

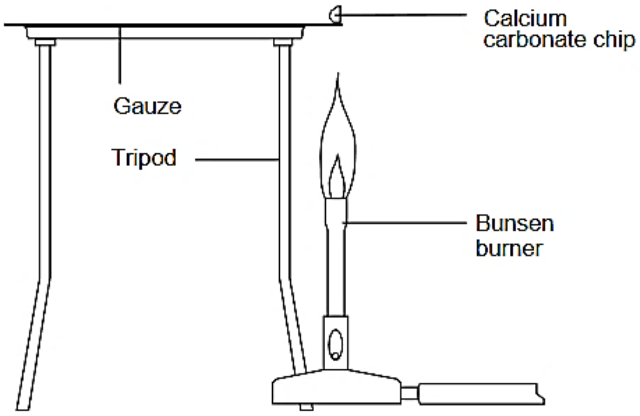
- Phlogiston is found in all combustible substances
- Substances burn better when they contain more phlogiston
- The combustion process releases phlogiston to air, which appears in the form of fire.
- Ores and metals may not produce flames of fire as phlogiston is released slowly and gradually.
- The ash left behind after heating is called calx
- Calx is less dense than the metal because it has lost phlogiston

The theory had the power to explain a number of observations, particularly reactions that were economically significant at the time. The below will demonstrate the power of phlogiston in explaining the change in the mass of heated limestone:

Demonstration: Heating Limestone

Smelting is the process of extracting a metal from its ore by using heat.

Calcium carbonate, known as limestone, is heated using a Bunsen Burner as shown in the diagram below.



1. Predict, based on phlogiston theory, what will happen to its mass?

Demonstration:

Your teacher will demonstrate the experiment below:

Procedure:

- Use 2 limestone chips and weigh them. Record the measurement.
- Place the limestones over the gauze surface and heat them using the Bunsen Burner for 10 minutes.
- Use the tongues to remove the chips and reweight them. Record the measurement.

2. Record your observations:

Mass of the sample before heating: …………………/g

Mass of the sample after heating: ………………../g

3. **Explain** whether the results confirm or reject the theory of phlogiston.

4. **Explain** whether you need more evidence to reach a stronger conclusion.

5. **Describe** how George Stahl would use the data in this experiment to justify the theory of phlogiston.

6. Think of the prediction you made before the demonstration. What made you formulate this prediction?

7. Calcium carbonate breaks down into calcium oxide and carbon dioxide.

   i. Write the word equation for the chemical reaction

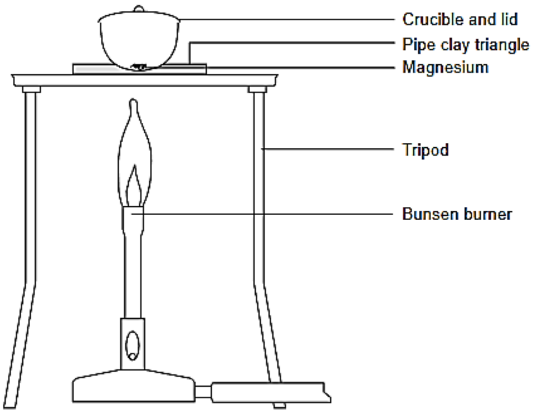
   ii. The balanced chemical reaction is outlined below:

$CaCO_3$ (s) → CO_2 (g) + CaO (s)

The symbol (g) implies that CO_2 is in the gaseous state. Where does this gas go?

Antoine Lavoisier (1743-1794) was a French chemist, who was widely regarded as the father of modern chemistry. Lavoisier made significant contribution to chemistry when he challenged the theory of phlogiston to falsify it. He investigated burning of metals, and thought that their data proves that the theory is not quite right. Working with Sulfur, Lavoisier found its mass increases. However, according to phlogiston theory, the mass is supposed to decrease. Something was wrong here!

Experiment: Falsifying Phlogiston (Students work in groups of 4)



Experimental Set

Materials needed:

- Mg ribbon sanded to release the oxide layer.
- Bunsen Burner
- Crucible
- E-balance
- Clay triangle
- Crucible tongues

Procedure:

- Weigh the mass of the empty crucible (with its lid) and record the results below.
- Place the Mg ribbon inside the empty crucible (lid on) and weigh them on the e-balance. Record the results.
- Place the crucible (lid on) on the top of clay triangle above the Bunsen Burner. Heat for 15 minutes. Remove the lid occasionally and carefully to prevent any solid ash from escaping.
- After 15 minutes, transfer the heated crucible to the bench.
- Weigh the crucible after heating. Record the results.

Carefully record your results:

  - **Mass of the crucible + lid: ……………………………….. /g**
  - **Mass of crucible + lid + sample: ……………………………….. /g**

	Appearance of Sample	Mass of Sample /g
Start		
End		
		Difference in mass /g =

Post-Experiment Questions:

8. How did the mass of the sample change after heating?

9. When magnesium is heated, it reacts with oxygen to form magnesium oxide. Write the word equation of the reaction.

10. The balanced equation is: $2Mg\ (s) + O_2\ (g) \rightarrow 2MgO\ (s)$
 Based on the chemical reaction, explain why the mass of the Mg sample change in mass.

11. Explain whether your data reject or confirm the theory of phlogiston?

12. **Outline** how Lavoisier would use the data in this experiment to falsify the theory of phlogiston.

Reflective and Explicit Discussion

1- On what basis did you formulate your prediction in the start of the lesson (Question 1)? Explain whether all the students have the same prediction and explanation. Deduce whether scientists, in real life, form the same predictions and explanations.

2- Does the data validate or contradict the theory of phlogiston? How did you reach your conclusions? How do scientists reach their own conclusions?

3- Reflect on the outcome of the experiment:

    a. Based on the results of the experiments, explain whether your prediction in question 1 was write or wrong.
    b. Describe how this resembles the work of scientists in the real world.
    c. How do scientists adjust their hypothesis in light of new evidences?

5- How does this discussion show how science works?

Reference:

Tingle, M. (2014). *The logic of phlogiston*. RSC Education. https://edu.rsc.org/feature/the-logic-of-phlogiston/2000126.article

Name__________________________
Date___________________________

Handout 3: Factors Affecting the Rate of Reaction

Teaching Nature of Science Through Scientific Inquiry
Factors Affecting the Rate of Reaction

Pre-demonstration Questions: Think – Pair –Write - Share

1- How would you start a glowing stick?

2- What do you think you should do for the glowing stick to last longer?

3- What do you think you should do for the glowing stick to glow brighter?

4- **Initial prediction:** Which of the two glow sticks will glow brighter? Longer? Provide a reasoning for your prediction

Demonstration: The teacher places one glow stick in hot-water cup, and another in the cold-water cup for at least two minutes.

Post-demonstration Questions: Think – Pair –Write - Share

5- How does placing a stick in cold temperature affect its glow?

6- Why does the stick in a cold environment last longer while the stick in hot water glows brighter?

Investigation: Does the temperature of reacting substances affect the speed of reaction?

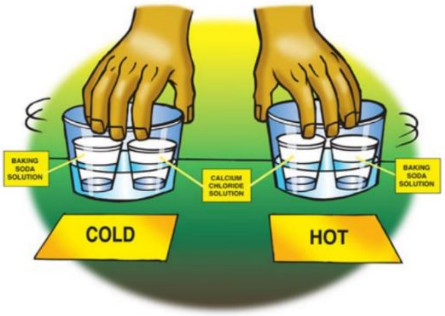
Material for each pair:

- Water; Calcium Chloride
- Baking Soda
- Graduated Cylinder
- Teaspoon
- 2 clear plastic containers
- 4 smaller clear plastic cups
- 2 small clear containers
- Hot water (40 – 50 ^{o}C)
- Ice water (0 – 5 ^{o}C)
- Masking tape
- Pen
- stopwatch

Procedure:

Preparing the baking soda solution:

- Use the masking tape and a pen to mark 2 plastic cups as baking soda solutions, and 2 cups as calcium chloride solutions.
- Use the graduate cylinder to add 20 mL of water in one of the baking soda cups.
- Add 2g of baking soda to the cup containing water and shake to dissolve.
- Pour half the baking soda solution into the other empty baking soda cup.



Preparing the calcium chloride solution:

- Use the graduated cylinder to add 20 mL of water into one of the calcium chloride cups.
- Add 2g of calcium chloride to the cup containing water and shake to dissolve.
- Pour half the calcium chloride solution into the other empty calcium chloride cup

Altering the temperature of the solutions

- Pour hot water into one of the containers, and cold water into the second. Make sure that the water is only filling ¼ of the container. Those will be the hot and cold-water baths.
- Place a one baking soda and one calcium chloride solution in the hot water bath, and place the other two solutions in the cold-water bath. Keep them for 30 seconds.

Add the solutions

- At the same time, add the cold solutions to each other, and the hot solutions to each other. Use the stopwatch to observe and record the time for a visible precipitate to form.

Record your findings below:

Condition	**Quantitative data (Time /sec)**	**Qualitative data** *Fizzing (Longer/Shorter)* *Brightness (more/less intense)*
Reactants at HIGHER temperature	**What is the time needed for the precipitate to become visible?** ________________	
Reactants at LOWER temperature	**What is the time needed for the precipitate to become visible?** ________________	

Questions:

7- Based on the result, how does the temperature of the reactants affect the rate of reaction?

8- Based on your results, explain your qualitative data.

9- Based on your results, explain how do the findings of the experiment help you understand the "glowing stick" demonstration.

Open-ended Questions:

10- Think of the prediction you made before the demonstration of the glowing sticks. **Explain** what made you formulate this prediction?

11- Did all the students formulate the same prediction? Why do you think so?

12- How did you reach your conclusion regarding the effect of temperature on rate of reaction?

13- Show how the results of the activity supported or contradicted your initial prediction.

Reflective and Explicit Discussion: A Teacher Guided Discussion:

1- On what basis did you formulate your prediction in the start of the lesson? How did the students' predictions differ from each other? How do you think scientists' predictions and explanations vary in real-life scenarios?

2- Explain how you reached your conclusion? How do scientists reach their own conclusions?

3- Reflect on the outcome of the experiment:
   a. After doing the experiment, did anyone find that their initial prediction was invalid? Did they change their mind? Explain.
   b. How does this process reflect the work of scientists? How do scientists change their minds?

4- How does this discussion show how science works?

Name__________________________

Date___________________________

Handout 4: Criteria of Purity – Density

Teaching Nature of Science Through Scientific Inquiry
Investigating the Purity of Substances

Purpose: Investigating the nature of different metals by determining their densities.

Pre-demonstration Engagement:

From the material in front of you, find the four metal plates.

1- Initial Prediction: Do you think that the metals are of the same mass? Are they of the same material? Explain.

2- Use the e-balance to measure the mass of each plate. Record your findings in table 1:

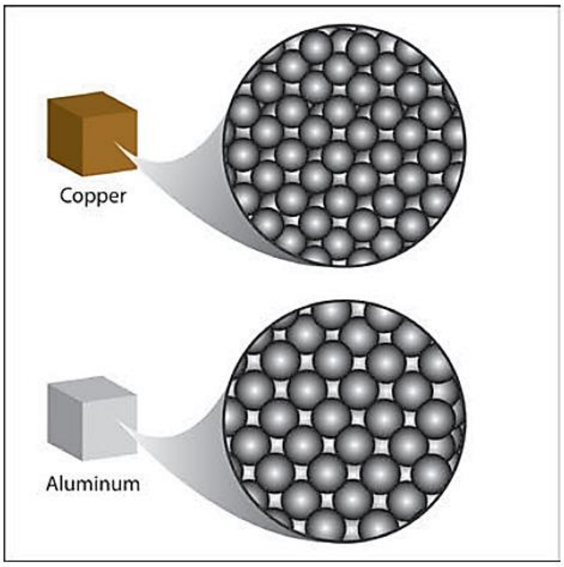
Metal Plate	Mass (in g)
Plate 1	
Plate 2	
Plate 3	
Plate 4	

Table 1

3- How can objects of the same size and shape have different masses?

Demonstration:

The teacher places a copper and an aluminum cube on a digital balance. Even though the cubes are of the same volume, the data on the digital balance indicates that they have different masses. Both cubes are solid, pure, and are not empty from inside.



Look at the figure on the right showing copper and aluminum cubes and their atoms.

The copper atoms appear to be slightly bigger in size than the Aluminum atoms.

Hence, there appears to be fewer copper atoms in the copper cube than aluminum atoms in the aluminum cube.

<u>Hint: Even if the aluminum atoms are larger, the do not have to be heavier.</u>

Use the THINK – PAIR – WRITE – SHARE routine to answer the questions:

4- If there are fewer copper atoms in the cube, why does the copper cube weigh more?

5- Think back of the initial prediction in question (1), does the demonstration validate or contradict your initial prediction?

Investigation: Your goal is to use density to identify the metallic nature of each of the plates.

Materials for each group:

- Four metallic plates numbered from 1 to 4 (18 cm^3 each)
- Calculator

Procedure:

- Insert the mass of each plate from the data the table on table 1.
- Calculate the density of each plate using the formula d=m/v
- Record your values in the table below.

Hint: Keep the "material" column empty. We will refer to it later.

Plate	Mass (g)	Volume (cm^3)	Density (g/cm^3)	Material
1		18		
2		18		
3		18		
4		18		

Table 2

Material	Approximate Density
Aluminum	2.9
Brass	8.8
Copper	9.3
Steel	8.2
Zinc	7.1
Nickle	8.9
Iron	7.8

Table 3

6- Use the information given in table 3 to identify the material that makes up each plate. Write the name of each material in table 2.

7- Even though the plates have the same color, size and shape, they are made of different materials. Explain.

8- If a metal has a higher density, what can you hypothesize about the mass of the atoms making it up?

Open-ended Questions: Students answer in writing

9- Think of the prediction you made before finding the mass of each plate. **Explain** what made you formulate this prediction?

10- Did you (or any of your classmates) change your mind with respect to the nature of plates' materials? How?

11- **Explain** how you reached your conclusion regarding the nature of each metallic plate.

12- After finishing this lab session and answering all the questions, can you **describe** how science works and how scientists construct their knowledge?

Reflective and Explicit Discussion: A Teacher Guided Discussion:

1- On what basis did you formulate your initial prediction in the start of the lesson? How did the students' predictions differ from each other? How do you think scientists' predictions and explanations vary in real-life scenarios?

2- Did you (or any of your classmates) change your mind regarding the nature of each material? Why? How do you think scientists change their minds?

3- Explain how you reached your final conclusion regarding the material making up each plate. How do scientists reach their own conclusions?

4- Reflecting on the outcome of the experiment:
  a) Based on the data produced, can you explain whether your initial prediction was right or wrong?
  b) How does this process reflect the work of scientists? How do scientists change their minds?

5- How does this discussion show how science works?

Name___________________________

Date___________________________

Handout 5: Carbon dioxide gets stoned

Teaching History of Science Through Socioscientific Issues

Carbon dioxide gets stoned

Objective: In this lesson, you will investigate the carbon capture and storage (CCS) technology. Using GRASP model, you will work in groups of 3-4 to discuss, analyze, and evaluate the technology using the article provided. Your task will include a comprehensive examination of the technology's strength, limitation, impact, and varying scientific viewpoints.

The full article could be accessed and downloaded through this link: Carbon dioxide gets stoned

The article is also added to page 25 to be accessed and utilized by offline users.

The GRASP model:

Goal: Your goal is to actively get engaged with a text that addresses carbon capture technology, evaluate its strength and limitations, understand its impact, and discuss different scientific views. You will be working in groups to search, discuss, and present your findings.

Role: You are a member of a team of environmental scientists. You will present your analysis and recommendations to your classmates.

Audience: The audience will be your classmates, your teacher, and your debate club, if applicable. You will present your finding and interact with the audience to lead the discussion.

Situation: As a team, you have been assigned to investigate CarbFix technology presented in this article. It involves capturing CO_2 from air and injecting it in basalt rocks to reduce its concentration in the atmosphere, mitigating global warming.

Product: Your product could be any of the following:

- A3 mind map
- Power Point presentation
- Poster (Canvas)

The product must include:

1- An introduction for carbon capture including its definition

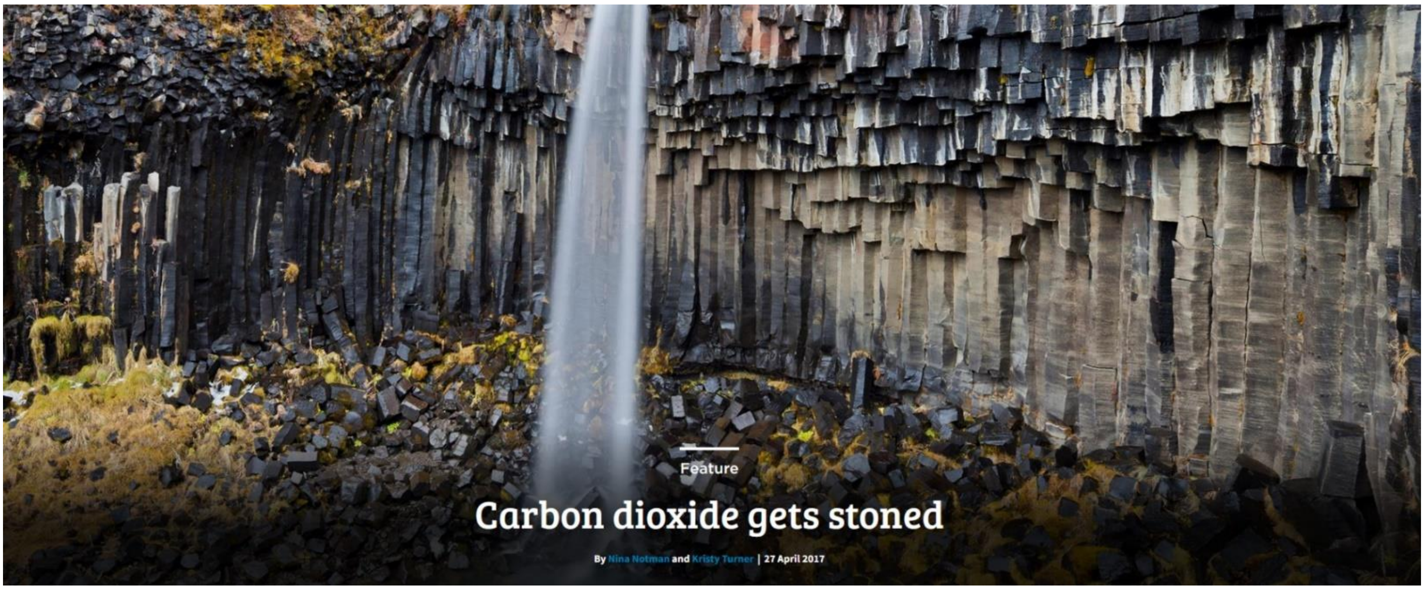
2- Assembling and present the ball and stick model of carbon dioxide, sulfuric acid, and calcium carbonate.
3- Definition of terms that you find unfamiliar. You can use search engines to reach the definitions.
4- Summary of strength and limitations of CarbFix
5- Scientific development may have social, economic, and/or environmental impact. Use the information in the article to discuss the impact of carbon capture on these categories. Support your answer with evidence.
6- Would you recommend the use of carbon capture technology? Justify your answer and support it with evidence.
7- Other scientists disagree with your recommendation above. Discuss how could they explain their position to convince you of their stance?
8- Explain how scientists may have different opinions on the use of carbon capture even though they are all examining at its various effects. Why do you think conflicting opinions might exist?
9- Explain whether it’s possible to revise your understanding in regards to utilizing CarbFix in the future.

End of task

Reflective and Explicit Discussion

This is a teacher guided whole class discussion. The role of the teacher is to facilitate the discussion and to prompt the students to elaborate more in their explanations. The teacher needs to challenge the students to improve their understanding of nature of science. It is not recommended that the teacher provides answers, but steer the discussion to reach desired understanding.

1- On what basis did you formulate your position after reading the article? **Discuss** whether the government and the researchers would have the same position?
2- Explain how scientists reach their conclusions.
3- The technology of carbon fixing developed over time, particularly in finding alternative ways to inject carbon dioxide into basalt with a reduce cost. Given the new breakthrough that may result in having carbon dioxide captured with reduced cost, explain how researchers and government leaders may change their mind in relation to utilizing this technology.
4- Describe how one can generalize from this discussion how science works?



Carbon dioxide gets stoned

Education in Chemistry
May 2017
rsc.li/EiC317-carbon-capture

Nina Notman meets the teams exploring the potential of locking Earth’s excess carbon dioxide away for millions of years by turning it into rock

Iceland is widely touted as a leader in green energy, generating 100% of its electricity from renewable sources. It might come as a surprise, then, to hear that this sparsely populated country has a huge carbon dioxide emissions problem. This is because although Iceland’s two electricity sources – hydropower and geothermal – are promoted as being clean, they do still cause the emission of significant amounts of carbon dioxide and other gases.

A secondary issue is that Iceland produces a lot of electricity for industrial purposes, explains Eric Oelkers, professor of geochemistry at University College London. The availability of copious amounts of electricity at consistently low prices has attracted the global aluminum production industry to the country. The extraction of aluminum from aluminum ore is a very energy-hungry process. ‘Iceland imports aluminum ore, smelts it and then exports the aluminum again,’ Eric says.

Volcano power

Eric has been overseeing a novel initiative to reduce emissions at the country’s largest geothermal power plant. Hellisheidi produces electricity and hot water from the Hengill central volcano, with a capacity of 300 MW of electricity and 120 MW thermal.

The initiative, CarbFix, is a carbon capture and storage (CCS) project with a twist. Conventionally, the carbon dioxide captured using CCS is stored underground in depleted oil and gas reservoirs or other locations where it is unlikely to leak back out again. However, Iceland's volcanic nature means it doesn't have any nicely sealed underground reservoirs suitable for long-term gas storage. Eric's team therefore needed to develop an alternative approach.

Instead, the team is injecting carbon dioxide captured at Hellisheidi into basalt, a reactive rock rich in divalent cations such as calcium and iron. Here it reacts to form the carbonate mineral calcite (CaCO3). This locks the gas away for millions of years in an environmentally benign manor. 'The only solution there was for Iceland was to get the carbon dioxide to react with basalts to make carbonated rocks,' Eric explains. 'Once the carbon dioxide is mineralized it stays there forever: the average age of a carbonate rock in the crust is 200 million years old.'

Source: © Johann Helgason/Shutterstock
Hellisheidi geothermal power plant in Iceland

The project started in 2006, and has been through many design and testing stages. In 2016, the team reported in Science surprising findings from its final pilot plant study at Hellisheidi. The carbon dioxide they had injected into the basalt had reacted to form rock in less than a year; it had been predicted this process would take many years.
But while the technology development has proceeded near perfectly, it hasn't been a smooth ride getting this far. 'There have been some twists and turns in the story,' Eric says. 'Over the years it became clear that there is no financial model to make carbon capture and storage work. Many of these projects globally started shutting down. It

costs money to do and if no government was going to force people to do it, nobody would.'

The Icelandic government, however, was happy to fund the removal of a second hazardous gas from Hellisheidi's flue gases: hydrogen sulfide (H2S). Unlike carbon dioxide, hydrogen sulfide has an immediate impact on the local population. 'It smells of rotten eggs,' Eric explains. 'Because of increasing energy production, the levels of hydrogen sulfide were beginning to get too high in some parts of Iceland. What we did is expand the capture and storage of carbon dioxide to capture and store, simultaneously, hydrogen sulfide and carbon dioxide.' Hydrogen sulfide, when injected into basalt rocks, rapidly forms pyrite (FeS2), also known as fool's gold. The hydrogen sulfide part of this project is called SulFix.

Since 2014, the CarbFix-SulFix project has been operating on a commercial scale. 'About two-thirds of the gases produced by the plant are currently injected and this will be upscaled to 100% within about a year,' Eric says. Without the capture technology, Hellisheidi emits about 40,000 tonnes of carbon dioxide and 12,000 tonnes of hydrogen sulfide each year. To put this in context, this is about 5% of the emissions that would come from a similarly-sized coal-powered plant.

The technology

The first generation of the CarbFix technology involved separating the carbon dioxide from the flue gases, dissolving it in water and then injecting it into basalt rock. Water reacts with carbon dioxide to form carbonic acid (H2CO3), which plays an important role in the mineralization process. In the final pilot study reported in Science, the gas from the plant was also combined with extra carbon dioxide brought in from elsewhere, including some spiked with heavy carbon (carbon-13) to aid monitoring of the mineralization process. (Samples are still routinely taken from wells to monitor the pH and geochemistry at the injection site.)

The request to capture and inject hydrogen sulfide from the flue gases as well allowed the process to be simplified. 'What we do now is take the exhaust gas from the power plant and put it through something called a sparger, which is a fancy name for a shower,' says Eric. 'Raining water on the exhaust causes the carbon dioxide and hydrogen sulfide to dissolve. We then take this pressurized water and inject it directly into the ground. It's very simple.' The process has been shown to work with both fresh and seawater.

Energy is the only major cost associated with the project once the system has been installed. 'Energy is used in the inner pressurization of system used to dissolve the carbon dioxide and hydrogen sulfide in the gas,' Eric explains. But the amount of energy required is far less than for conventional CCS units that inject the gas into disused oil wells and the like. It has been estimated the CarbFix-SulFix process will use up approximately 0.2% for the power produced at Hellisheidi. This compares well to the 3 to 10% typically reported for conventional CCS units at coal- and gas-fired power plants. This equals significant cost savings. 'The cost of doing this is approximately $25 a tonne, compared to in the order of $60 to $120 a tonne with conventional technology,' says Eric.

The success of this mineralization process opens the doors for the CarbFix-SulFix setup to be replicated at other power plants. 'Basalts are very abundant,' says Eric, both on land and under the sea. 'Pretty much all the ocean floors are basalts, which is an advantage because people don't seem to want carbon dioxide injected underneath their homes,' he adds. Ultimately, however, Eric believes that politics will determine whether the technology is eventually used elsewhere.

Meanwhile, in January 2017, his team started to develop their technology to capture carbon dioxide directly from the air. 'Less than half of the carbon dioxide that goes into the atmosphere comes from power plants. More than half comes from cars, jet planes, etc. We're going to have to air capture eventually,' he says. Again, this technology would be suitable for any site near basalts and with lots of water available. 'We're teaming up with an air capture company to do this on the coastline of Iceland.'

Over the pond

Eric's team are not the only ones looking at the potential of capturing carbon dioxide and turning it into rock. The CarbFix project is, however, by far the most advanced. To date, only one other team – the Big Sky Carbon Sequestration Partnership at Montana State University in the US – has taken the testing of this technology out of the lab and into the field.

In 2013, the Big Sky team, together with the not-for-profit organization Battelle, injected around 1000 tons of carbon dioxide into basalt rock at a site in Washington State. 'This was a moderate scale pilot where we injected purchased carbon dioxide, we didn't capture it. It was to prove the principle,' explains the project's director Lee Spangler. 'The purpose of the pilot was to field test injection of carbon dioxide into basalts, and see in situ what the chemical reactivity was, and how quickly that carbon dioxide would start turning into rock.'

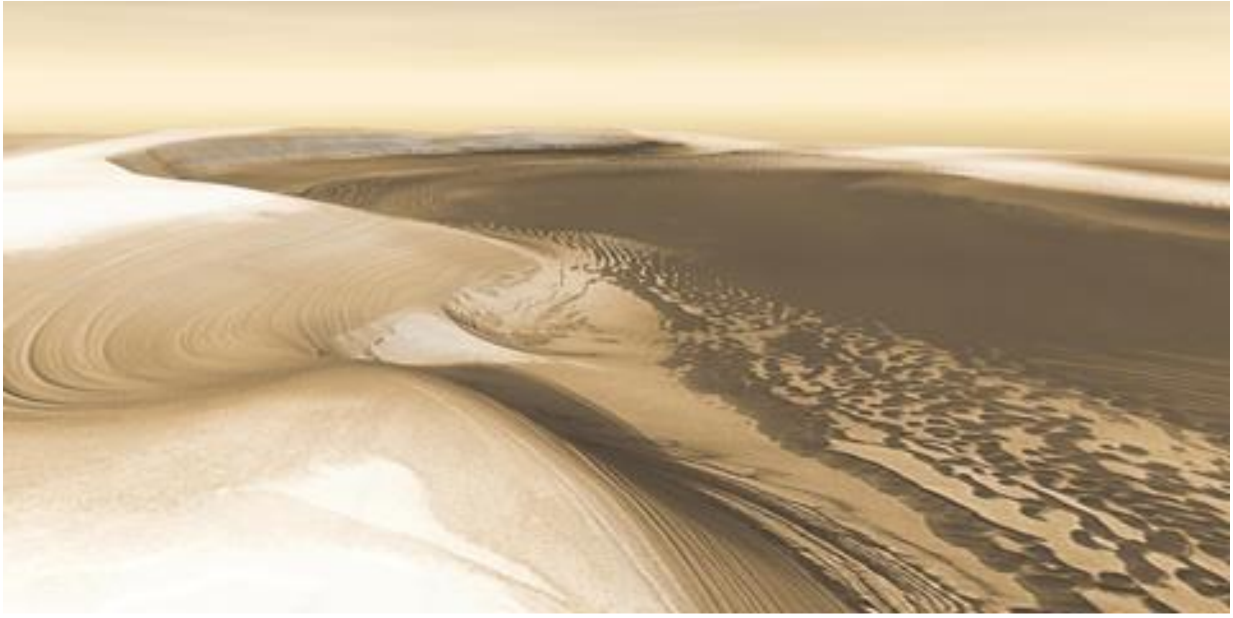
'The major difference between what we were doing and what has been done in Iceland is that the Icelandic team dissolve the carbon dioxide in water or brine before it is injected, whereas at the pilot we performed, it was injected as pure carbon dioxide gas,' Lee says.

There is some brine or water in basalt rock naturally, but the absence of the step to pre-dissolve the carbon dioxide could change the chemistry of the mineralization process. 'Carbon dioxide dissolved in water becomes carbonic acid, and the reactivity of that can be different to injecting free phase carbon dioxide,' says Lee. 'Battelle laboratory tests showed it would still rapidly convert to minerals, but we wanted to check it in situ. The advantage of injecting it as pure carbon dioxide is that you don't have to go through that step of dissolving it in water.' Removing the pressurized water step will obviously reduce costs.

The pilot was a success, and sampling and monitoring at the site continued for a further 18 months following the injection process. The funding for this project has now ended and Lee’s team have turned their attention to conventional CCS. The so-called Kevin Dome Project is testing the potential of storing gaseous carbon dioxide long-term at an underground site in Montana.

How Mars turned to rock

Although the concept of capturing carbon dioxide from flue gases, or the air, and turning it into rock may sound a little out-there, it is a process that occurs naturally on Earth – albeit very slowly. Researchers in Glasgow also believe the same process may have been responsible for the dramatic thinning of the atmosphere on Mars a few billion years ago. The thin layer of gas that surrounds this planet contains around 95% carbon dioxide. Evidence, such as dried up river beds on its surface, suggests around 4 billion years ago the atmosphere was much thicker – thick enough to support life in fact.



Source: © NASA/JPL/Arizona State University, R. Luk

Mars has bright polar caps of ice that are easily visible from telescopes on Earth. A seasonal cover of carbon-dioxide ice and snow is observed to advance and retreat over the poles during the Martian year.

It is not known for sure what happened to all that gas, but one theory is some of the carbon dioxide was sucked into rocks and mineralized. In 2013, scientists at the University of Glasgow reported evidence to support this claim; they found veins of carbonate minerals in a Martian meteorite thought to have landed on Earth around 3000 years ago.

‘In the laboratory we are now using high-pressure, high-temperature experiments to recreate approximately the Martian environment at that time,’ explains PhD student Adrienne Macartney. ‘The idea is to try to chemically and visually replicate the kind of carbonates we see in the Martian meteorites, with the general notion being if you’re chemically and physically replicating them, then perhaps the conditions you’ve used are similar to those on very early Mars.’

The similarities between these two research fields is obvious. 'Mars is an example where we know a very similar process to CarbFix's has happened naturally. But it's happened on a very large, planetary scale. The areas we are looking at are hundreds of thousands of kilometres of potential reaction site, instead of just like couple of square kilometres in Iceland,' Adrienne says.

Studying the natural process on Mars might also help us predict the potential impacts of CCS. 'The work to understand the extent to which it potentially has affected the atmosphere on Mars might be helpful to help quantify the effects which this kind of technique might have on Earth. At the moment, there's really not much dialogue between carbonate researchers on Mars and Earth.'

This is something Adrienne hopes to address. 'We have an enormous amount of expertise in a lot of the same problems, so we may just find there's a lot more efficiency in solving the terrestrial climate issues if we worked together.'

Article by Nina Notman, a science writer based near Baltimore, US.

Further reading

- The CarbFix project: bit.ly/carbfix-project
- Basalt pilot project: bit.ly/big-sky-basalt
- University of Glasgow, planetary science and astrobiology research group: solarsystemrocks.org/current-research

Name________________________
Date________________________

Handout 6: Acid rain not all bad

Teaching History of Science Through Socioscientific Issues

Acid rain not all bad

(Bowen, 2019)

Acid rain can benefit the environment by blocking one of the most powerful greenhouse gases, scientists said yesterday.

Research led by Vincent Gauci, from the Open University's department of earth sciences, shows that the Sulphur in acid rain dramatically reduces the natural production of methane, responsible for an estimated 22% of the greenhouse effect that is causing global warming.

Acid rain, produced by industrial emissions of Sulphur dioxide, destroys forests and kills fish and other aquatic animals.

Over the past 20 years European industry has become much cleaner, and the EU is committed to further emission reductions by 2010.

But the study, published in the journal Proceedings of the National Academy of Sciences, suggests it might be unwise to halt acid rain completely.

Dr Gauci's research showed that other bacteria which thrive on Sulphur compete with the methane-makers. Their numbers are so boosted by acid rain that they can significantly reduce methane generation from wetlands. Dr Gauci's team carried out experimental research on wetlands in Morayshire, Scotland, to test the effect of Sulphur *depositions on methane emissions. The data were then combined with a computer model from the American space agency, Nasa, to provide a global picture.*

It showed that the effect of acid rain from 1960 to 2030 could reduce methane emissions to pre-industrial levels.

"The effect more than compensates for the increase in methane emission that would be expected as wetlands become warmer," said Dr Gauci. "In effect, acid rain is acting like a lid on the largest methane source. "

https://www.theguardian.com/science/2004/aug/03/sciencenews.research

Reporter, G. S. (2018, February 14). Acid rain not all bad. *The Guardian*.

https://www.theguardian.com/science/2004/aug/03/sciencenews.research

Read the text well before answering the questions below:

1- There are a number of ways to address the issue of acid rain:

A. We may not take any action to address the matter, because, after all, acid rain appears to be beneficial to the environment.
B. Reduce the production of pollutant gases by controlling the combustion of fossil fuels. This will mean that we will be using more public transportation rather than using our private cars, and the government will impose more taxes on importing cars.
C. Reduce the production of pollutant gases by treating our fuel before consumption. This is an expensive process and the citizens will be paying for this in an indirect way.

   a. Which suggestion would you recommend?
   b. Justify your answer.

2- Other scientists disagree with your recommendation above. **Explain** how could they explain their position to convince you of their stance?

3- After the emergence of evidence that concludes that acid rain is not all bad, did you change your mind about acid rain? **Explain**.

4- **Explain** how scientists may have different opinions on the matter of acid rain even though they are all examining at its various effects.

5- Based on your knowledge of the adverse effect of Acid Rain, and in reference to the article you just read, **determine** whether the governments need to take serious measures to stop Acid Rain.

6- **Explain** whether it’s possible to revise your understanding in regards to the issue of acid rain in the future.

7- **Show**, from the article, why scientists may consider revising their knowledge on acid rain.

8- **Show**, from the article, how scientists rely on observations and experimental results to reach conclusions.

Reflective and Explicit Discussion

1- **Explain** the rationale behind the position you formulated in question 1.

2- **Explain** how scientists reach their conclusions.

3- Given the new evidence that acid rain is not entirely harmful, describe how your views on acid rain have changed. Additionally, **explain** how this process reflects the way scientists revise their understanding based on new findings.

4- **Describe** how one can generalize from this discussion how science works?

REFERENCES

Abd-El-Khalick, F. (2012). Nature of science in science education: Toward a coherent framework for synergistic research and development. *Second International Handbook of Science Education*, 1041-1060.

Abd-El-Khalick, F. (2002). The Influence of a Philosophy of Science Course on Preservice Secondary Science Teachers' Views of Nature of Science.

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education, 88*(5), 785-810.

Abd-El-Khalick, F., & Boujaoude, S. (2003). Lebanese students' views of the nature of science. *Mediterranean Journal of Educational Studies*, 8(1), 61-79

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education, 22*(7), 665-701.

Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 37*(10), 1057-1095.

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.

Aikenhead, Glen & Ryan, Alan. (1992). The Development of a New Instrument: 'Views on Science—Technology—Society' (VOSTS). *Science Education*. 76. 477 — 491. 10.1002/sce.3730760503.

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education*, *95*(3), 518-542.

Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature of science: Integrating student inquiry, historical cases, and contemporary cases in classroom practice. *Science Education*, *98*(3), 461-486.

American Association for Advancement of Science. (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.

Andrewgenn. (2014, February 18). *Greeks*. Dreamstime. https://www.dreamstime.com/royalty-free-stock-photo-greeks-two-greek-men-talking-front-building-image36996735

Bell, R. L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it? Impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching*, *40*(5), 487-509.

Bell, R. L., Matkins, J. J., & Gansneder, B. M. (2011). Impacts of contextual and explicit instruction on preservice elementary teachers' understandings of the nature of science. *Journal of Research in Science Teaching*, *48*(4), 414-436.

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

Bowen, J. (2019). Acid rain & climate change are connected, here's how. Adirondack Council Conservation Fellow. https://www.adirondackcouncil.org/page/blog-139/news/acid-rain—climate-change-are-connected-heres-how-1267.html

Burgin, S. R., & Sadler, T. D. (2016). Learning nature of science concepts through a research apprenticeship program: A comparative study of three approaches. *Journal of Research in Science Teaching*, *53*(1), 31-59.

Central Association for Science and Mathematics Teachers. (1907). A consideration of the principles that should determine the courses in biology in secondary schools. *School Science and Mathematics*, 7, 241–247.

Chalmers, A. (2013). *What is this thing called science?* McGraw-Hill Education (UK).

Chang, K. K. M. (2024, May 10). *Georg Ernst Stahl | German Chemist, Physician & Philosopher*. Encyclopedia Britannica. https://www.britannica.com/biography/Georg-Ernst-Stahl

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education*, *15*, 463-494.

Clough, S. (2003). *Beyond epistemology: A pragmatist approach to feminist science studies*. Rowman & Littlefield.

Dogan, N., & Abd-El-Khalick, F. (2008). Turkish grade 10 students' and science teachers' conceptions of nature of science: A national study. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *45*(10), 1083-1112.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young People's Images of Science*. McGraw-Hill Education (UK).

Duschl, R. A., & Grandy, R. (2013). Two views about explicitly teaching nature of science. *Science & Education*, *22*, 2109-2139.

Eastwood, J. L., Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing nature of science instruction in socioscientific issues. *International Journal of Science Education*, *34*(15), 2289-2315.

Fouad, K. E., Masters, H., & Akerson, V. L. (2015). Using history of science to teach nature of science to elementary students. *Science & Education*, *24*, 1103-1140.

Gandolfi, H. E. (2021). “It’s a lot of people in different places working on many ideas”: Possibilities from global history of science to Learning about nature of science. *Journal of Research in Science Teaching*, *58*(4), 551-588.

Helmold, J. (2024). How did 139emocritus discover the atom? Developing atomic history. *AcademicHelp.net*. Available at: https://academichelp.net/humanities/philosophy/democritus-discover-the-atom.html (Accessed: 18 July 2024).

Herman, B. C. (2018). Students’ environmental NOS views, compassion, intent, and action: Impact of place-based socioscientific issues instruction. *Journal of Research in Science Teaching*, *55*(4), 600-638.

Hodson, D., & Wong, S. L. (2014). From the Horse’s Mouth: Why scientists’ views are crucial to nature of science understanding. *International Journal of Science Education*, *36*(16), 2639-2665.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, *20*, 591-607.

Irwin, A. R. (2000). Historical case studies: Teaching the nature of science in context. *Science Education*, *84*(1), 5-26.

Jenkins, E. W. (1994). HPS and school science education: remediation or reconstruction? *International Journal of Science Education*, *16*(6), 613-623.

Kang, S., Scharmann, L. C., & Noh, T. (2005). Examining students’ views on the nature of science: Results from Korean 6th, 8th, and 10th graders. *Science Education*, *89*(2), 314-334.

Kennedy, M. (2016, April 20). Lead-Laced Water In Flint: A Step-By-Step Look At The Makings Of A Crisis. *NPR*. https://www.npr.org/sections/I-way/2016/04/20/465545378/lead-laced-water-in-flint-a-step-by-step-look-at-the-makings-of-a-crisis

Khishfe, R. (2023). Improving students’ conceptions of nature of science: A review of the literature. *Science & Education*, *32*(6), 1887-1931.

Khishfe, R. (2020). Retention of acquired argumentation skills and nature of science conceptions. *International Journal of Science Education*, *42*(13), 2181-2204.

Khishfe, R. (2017). Consistency of nature of science views across scientific and socio-scientific contexts. *International Journal of Science Education*, *39*(4), 403-432.

Khishfe, R. (2014). Explicit nature of science and argumentation instruction in the context of socioscientific issues: An effect on student learning and transfer. *International Journal of Science Education*, *36*(6), 974-1016.

Khishfe, R., & Abd-El-Khalick, F. (2002). 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), 395-418.

Klopfer, L. (1969). Science education in 1991. *School Review, 77*(3/4), 199-217. https://doi.org/10.1086/442875

Klopfer, L. E. (1964). *History of science cases*. Science Research Associates.

Lau, K. C., & Chan, S. L. (2013). Teaching about theory-laden observation to secondary students through manipulated lab inquiry experience. *Science & Education*, *22*(10), 2641-2658.

Lederman, N. G. (2013). Nature of science: Past, present, and future. In *Handbook of Research on Science Education* (pp. 831-879). Routledge.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In *Handbook of Research on Science Education* (pp. 831-879). Routledge.

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*(4), 331-359.

Lederman, N. G., & Abell, S. K. (Eds.). (2014). *Handbook of Research on Science Education* (Vol. 2, pp. 600-620). New York, NY: Routledge.

Lederman, N. G., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. *Science Education*, *74*(2), 225–239. https://doi.org/10.1002/sce.3730740207

Lee, M. K., & Erdogan, I. (2007). The effect of science–technology–society teaching on students' attitudes toward science and certain aspects of creativity. *International Journal of Science Education*, *29*(11), 1315-1327.

McComas, W. F., Clough, M. P., & Nouri, N. (2020). Nature of science and classroom practice: A review of the literature with implications for effective NOS instruction. *Nature of Science in Science Instruction: Rationales and Strategies*, 67-111.

National Research Council, Division of Behavioral, Board on Science Education, & Committee on a Conceptual Framework for New K-12 Science Education Standards. (2012). *A framework for K-12 science education: Practices, Crosscutting Concepts, and Core Ideas*. National academies press.

National Research Council, Division of Behavioral, Board on Science Education, & National Committee on Science Education Standards. (1996). *National Science Education Standards*. National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. National Academies Press.

Paraskevopoulou, E., & Koliopoulos, D. (2011). Teaching the nature of science through the Millikan-Ehrenhaft dispute. *Science & Education*, *20*, 943-960.

Peters, E. E. (2012). Developing content knowledge in students through explicit teaching of the nature of science: Influences of goal setting and self-monitoring. *Science & Education*, *21*, 881-898.

Project 2061 (American Association for the Advancement of Science). (1993). *Benchmarks for Science Literacy*. Oxford University Press.

Reporter, G. S. (2018, February 14). Acid rain not all bad. *The Guardian*. https://www.theguardian.com/science/2004/aug/03/sciencenews.research

Rubba, P. A., & Andersen, H. O. (1978). Development of an instrument to assess secondary school students understanding of the nature of scientific knowledge. *Science Education*, *62*(4), 449-458.

Rudge, D. W., & Howe, E. M. (2009). An explicit and reflective approach to the use of history to promote understanding of the nature of science. *Science & Education*, *18*, 561-580.

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1-42.

Solomon, J., Scott, L., & Duveen, J. (1996). Large-scale exploration of pupils' understanding of the nature of science. *Science Education*, *80*(5), 493-508.

Tingle, M. (2024, April 11). *The logic of phlogiston*. RSC Education. https://edu.rsc.org/feature/the-logic-of-phlogiston/2000126.article

Wahbeh, N., & Abd-El-Khalick, F. (2014). Revisiting the Translation of Nature of Science Understandings into Instructional Practice: Teachers' nature of science pedagogical content knowledge. *International Journal of Science Education*, *36*(3), 425-466.

Walker, K. A., & Zeidler, D. L. (2007). Promoting discourse about socioscientific issues through scaffolded inquiry. *International journal of science education*, *29*(11), 1387-1410.

Yacoubian, H. A., & BouJaoude, S. (2010). The effect of reflective discussions following inquiry-based laboratory activities on students' views of nature of science. *Journal of Research in Science Teaching*, *47*(10), 1229-1252.

Yager, S. O., Yager, R. E., & Lim, G. (2006). The advantages of an STS approach over a typical textbook dominated approach in middle school science. *School Science and Mathematics*, *106*(5), 248-260.

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*(3), 343-367.

Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In *Handbook of Self-Regulation* (pp. 13-39). Academic press