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Contextualization of Nature of Science within the Socioscientific Issues Framework: A Review of Research

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Abstract

The aim of this paper is to examine the importance of contextualization of Nature of Science (NOS) within the Socioscientific Issues (SSI) framework, because of the importance to science education. The emphasis on advancing scientific literacy is contingent upon a robust understanding and appreciation of NOS, as well as the acquisition of socioscientific reasoning, skills, and values. Students' negotiations within SSI are influenced by a variety of factors related to NOS such as scientific knowledge, data interpretations and social interactions including an individuals' own articulation of personal beliefs. Since NOS and SSI have become fundamental constructs in science education, especially for achieving scientific literacy, it is conceptually important to highlight the rationale(s) behind the contextualization of NOS within the SSI framework. This paper reviews research that entails the integration of SSI with NOS, exploring the nuanced relationships between these two areas. We do this in three sections presenting key aspects of: (a) SSI in science education; (b) NOS in science education; and (c) contextualization of NOS in SSI.

Introduction

Over the past three decades, the fundamental premise of science education is not to teach more and more content, but rather to focus on what is essential to scientific literacy (SL) and to teach it more effectively and in a manner that authentically engages students. Science education reforms emphasize that students should have a practical and meaningful view of science. Having an informed understanding of the consequences of scientific developments on society is seen as a necessary condition for responsible members of society to make good decisions and to enrich their lives (Sadler, & Zeidler, 2009). The interdependence of science and society is at the heart of scientific literacy, a longstanding goal of science education. Scientific literacy is a complex, multidimensional construct that lies at the heart of contemporary reform documents in science education (Cakiroglu & Geban, 2016; Eurydice Network, 2011; National Research Council [NRC], 2012). Scientifically literate individuals should be able to negotiate and make decisions in everyday life issues that involve science content (Sadler, 2011). Further, a scientifically literate person is expected to be able to appreciate and understand the impact of science and technology on everyday life, make informed personal decisions about issues and topics that involve science, read and understand the essential points of media reports about matters that draw on science, and reflect critically on the information (PISA, 2015).

It is important to distinguish between science literacy (Vision I) and scientific literacy (Vision II) (Roberts, 2007; Roberts & Bybee, 2014). Vision I emphasizes aspects of academic content aligned within scientific disciplines. In contrast, Vision II emphasizes an approach broader in scope, involving personal decision making about contextually embedded science and social issues. Zeidler and Keefer (2003) and Zeidler and Sadler (2011) advocate the Vision II approach in a socioscientific issue-based (SSI) context in order to promote what they term as "functional scientific literacy." The perspective of this paper also aligns with the framework of Vision II in that we integrate SSI in a manner that entails understandings and practices connected to ''science-related issues'' in individuals' "real-life situations." In doing so, this progressive perspective promotes the *inclusion of SSI in order to promote a sociocultural view inherent to functional SL* (Zeidler, Sadler, Simmons & Howes, 2005). Figure 1 presents some of the key socioscientific elements promoting functional scientific literacy.

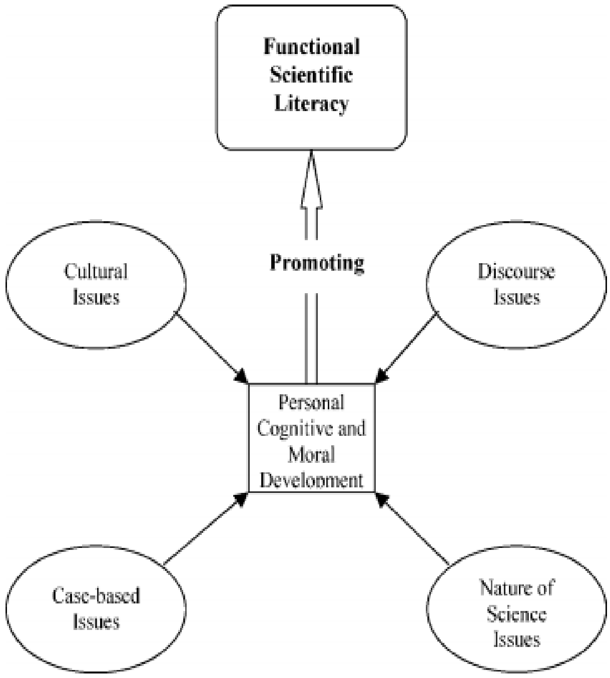

Figure 1. Components of functional scientific literacy (Adapted from Zeidler & Keefer, 2003, p.12)

The contributions of these components to learners' personal, cognitive, and moral development have been addressed in numerous research studies (e.g., Jiménez Aleixandre & Pereiro Munoz, 2005; Liu, Lin, & Tsai, 2011; Sadler, Chambers, & Zeidler, 2004; Zeidler and Keefer, 2003). It can be inferred from Figure 1 that each component contributes to personal, moral, and cognitive development, helping to promote functional scientific literacy. Many science educators advocate that all students need to be functionally scientifically literate in order to make informed judgments about decisions that impact the biological, physical and social environment (Deboer, 2000; Dillon, 2009; Holbrook, & Rannikmae, 2009; Ryder, 2001; Tippins, Mueller, van Eijck, & Adams; 2010).

The emphasis on advancing SL is also intricately connected to developing a robust understanding and appreciation of NOS, in addition to the acquisition of socioscientific reasoning, skills and values (Eastwood, Sadler, Zeidler, Lewis, Amiri, & Applebaum, 2012; Holbrook & Rannikmae, 2009). Students' negotiations on socioscientific issues are influenced by a variety of factors related to NOS such as scientific knowledge, data interpretations, and social interactions, inclusive of an individual's own articulation of personal beliefs (Sadler et al., 2004). Since NOS and SSI have become fundamental elements in science education (Sadler et al., 2004), especially for achieving scientific literacy, it is conceptually important to highlight the rationale(s) behind the contextualization of NOS within the SSI framework and address science subject matter embedded in SSI. The aim of this paper is to flesh out the importance of the actualization of a progressive vision for science education, entailing the integration of SSI for facilitating informed views of NOS.

In this paper, we examine the literature that considers the interrelationships between these two important areas of science education: the nature of science and socioscientific issues. We do this in three sections, aiming to: (a) highlight SSI in science education; (b) review key related NOS literature; and, (c) discuss literature that explores and highlights the rationale behind the contextualization of NOS in SSI.

Socioscientific Issues

As the 21st century progresses, science educators realize that important elements of SL include the ability to analyze, synthesize and evaluate information, consider multiple perspectives and lines of reasoning while examining scientific evidence, confronting ethical issues, and understanding connections inherent in socioscientific issues (Zeidler, 2001). "Socioscientific issues (SSI) involve the deliberate use of scientific topics that require students to engage in dialogue, discussion, and debate. They are usually controversial in nature but have the added element of requiring a degree of moral reasoning or the evaluation of ethical concerns in the process of arriving at decisions regarding possible resolution of those issues" (Zeidler & Nichols, 2009, p.1).

The socioscientific movement focuses mainly on allowing students to handle science-based issues that shape their current world and those which will determine possible future worlds that may likely confront them (Sadler, 2004). Incorporating SSI in science learning creates opportunity for the students to analyze others' points of view, emphasizes critical reasoning over memorizing, promotes the practice of participatory decision making, allows students to critically evaluate, argue, discuss and debate competing scientific claims, and promotes character and moral sensitivity of students to ethical issues (Zeidler, 2014). The use of SSI strategies challenges students to reevaluate their prior understandings, providing an opportunity for them to restructure their conceptual understanding of subject matter through personal experiences and social discourse (Zeidler & Nichols, 2009). The controversial nature of SSI and its relevance to society generate interest among students. Because of the apparent social, tentative and subjective nature of moral and ethical issues, teachers can more readily engage students in discussions that touch upon the many aspects of NOS (Walker and Zeidler, 2003). Using SSI as the point for launching such discussions has the potential to impact the daily lives of children in both formal and informal settings (Burek & Zeidler, 2015; Mueller & Zeidler, 2010). SSI can help students to understand aspects of NOS that contribute to decisions about important local, societal, and global issues to gain experiences negotiating the complex issues (Lee, et al., 2013).

Sadler (2011) reported that most of the classrooms he observed in the US primarily focused on teaching science content rather than engaging students in negotiation and decision making related to social issues that are conceptually connected to science content. He advocates the benefits of using SSI in science education in order to provide a personal and meaningful context for students' scientific learning. Classroom-based studies of SSI implementation and their outcomes are found to be particularly significant and thought to have important insights to offer the science education community (Sadler, 2011). Using SSI in science contexts encourages students to prioritize methods of inquiry while interpreting issues, making decisions, solving problems, and assessing scientific information and data. Furthermore, SSI may be a means of enhancing the primacy of citizenship goals for science education (Lee, Chang, Choi, Kim, & Zeidler, 2012).

Although the integration of SSI provides students with a forum to engage and connects them with relevant and socially shared issues, undeniably, the most critical element of this process is the teacher who can create opportunities for students to discover, explore, and acquire scientific knowledge for the investigation of an SSI unit. Teachers' attitudes towards the use of SSI for enhancing students' scientific literacy have an effect on their teaching practices (Sadler, Amirshokoohi, Kazempour & Allspaw, 2006). The SSI teacher, while not always setting a rigid or fixed agenda, helps to set the stage for student inquiry, often serving as a facilitator to ensure students stay on track in their discussions and constantly questioning the rationales for their underlying assumptions about the topic at hand. Such teachers accept that the exploration of ethics and values are a necessary and central part of instruction for achieving the challenging goal of scientific literacy in science education.

Sadler et al., (2006) investigated teachers' attitudes towards using SSI in science lessons and found five different distinct profiles of teachers including those who: 1) view embedding SSI in science teaching as important, view ethics and values as a necessary part of science instruction, and are able to implement these topics in their lessons without concern for administration's politics or interference; 2) having the same perspectives as teachers described above, but view administrative constraints as limiting their implementation; 3) understand the link between ethics and science in the context of SSI but are uncertain toward how to implement SSI-related strategies; 4) reject the interdisciplinary relationship of ethics and science; and 5) hold the same perspective as (a) -- but extend that position above and beyond science education suggesting that ethical reasoning and value formation are not only relevant to science, but all disciplines. In highlighting varying teachers' perspectives about implementing SSI in science lessons, the authors suggest proper emphasis on preservice teacher education and attention to working through real-life school and policy impediments that are important to address for teachers to feel comfortable with SSI instruction. Zeidler, Applebaum, and Sadler (2011) have also raised awareness of the importance of cultivating progressive teacher pedagogy for enacting an SSI classroom. In order to internalize a shift from traditional classroom practice to an SSI framework, it is crucial for teachers to be comfortable with the content, demonstrate an unwavering commitment to inquiry, and reflect on their own teaching practices. Encouraging active reflection and support by mentor teachers, or science educators can undoubtedly help teachers to evaluate and adjust their own practices.

Reviews of the previous research on SSI explicitly address the question of whether context matters for implementing SSI. The answer is consistently yes: context and curriculum does matter for SSI. Socioscientific issues-based instruction combines the use of controversial socially relevant real world issues with course content to engage students in their learning. Thus, context pertaining to the issue under consideration as it connects to the lives of students is of foremost importance to the quality of students' learning. The use of SSI for enhancing students' scientific literacy has been examined in various contexts such as: Web-based Inquiry Science Environment (WISE) by Slotta and Linn (2009) and Walker and Zeidler (2007); SSI-based Inquiry laboratory course by Karisan, Yilmaz-Tuzun & Zeidler (2015); and authentic contexts such as field trips by Tal and Alkaher (2010) and place-based environmental settings (Burek & Zeidler, 2015; Herman, Newton & Zeidler, 2015). The contexts for these studies do not have closed boundaries or well-structured problems that lead to a specific foreknown answer. Rather, the contexts are authentic challenges open to exploration, inquiry, and tap the integration of multiple disciplines. In these circumstances, students were engaged with ill-structured problems and were expected to be able to develop a position based upon research and discoveries on their own accord. Such research advances the claim that experience with SSI can produce changes in conceptual learning outcomes related to scientific understanding. Moreover, the literature has shown that SSI-based instruction increases student interest and motivation, improves the development of higher order thinking skills, and increases understanding of the nature of science. Moreover, the research on SSI-based learning has also been shown to improve students' content knowledge (Klosterman and Sadler, 2010).

Thus, within both formal and informal contexts, SSI has been used as a core means to develop functional scientific literacy. There has been a significant amount of research linking SSI with other important aspects of science education including argumentation (Jimenez Aleixandre & Pereiro Munoz, 2005), NOS (Sadler,et al., 2004), epistemology (Liu et al., 2011; Zeidler, Herman, Ruzek, Linder, & Lin, 2013), communication skills (Yoonsook, Yoo, Kim, Lee, & Zeidler, 2016), and reflective judgment (Zeidler, Sadler, Applebaum, & Callahan, 2009). All these areas of work also help demonstrate linkages between NOS and SSI in general and show how SSI can serve as a natural and effective context for the exploration of general and related contextualizations of NOS (Kampourakis, (2016). We begin describing those linkages below.

Nature of Science

While there is no singular consensus on a definition of NOS (Lederman, 2007), it is commonly expressed as the epistemology of science, a way of knowing science, or the values and beliefs inherent to the development of scientific knowledge (Abd-el-Khalick, Bell, & Lederman, 1998). To parse its meaning, researchers have proposed characteristics of scientific knowledge that include: 1) empirical nature of science; 2) theory and law; 3) subjectivity of science; 4) tentativeness of scientific theories and laws; 5) creativity and imagination; 6) inferential nature of science; and, 7) the social and cultural embeddedness of scientific knowledge. These characteristics are also known as NOS aspects, features, or components (Abd-El-Khalick et al., 1998; Lederman, 2007). Ultimately, it is desirable for students to develop mature or informed views on these components. Having informed views on these aspects requires students to understand that science is based on and derived from *observations* of the world, *interpretations* are made by using those observations, and scientists depend on *empirical* evidence. Beyond that, more nuanced views include the understanding that scientific explanations must be consistent with observed empirical evidence, a *law* is neither "better than" nor "above" a *theory*, and science is *subjective* which means scientists' experiences, prior knowledge, cultural background, expectations and biases, theoretical beliefs, and training affect their observations and conclusions. Informed conceptualizations of NOS are also congruent with the notion that while scientific knowledge is durable, it is also t*entative* and subject to change in the light of new evidence or new interpretation of existing evidence, and that scientists may conceptualize unobservable phenomena such as black holes, atoms, and operationalize constructs (e.g., species, electron-transport chain, intelligence) using their *imagination and creativity*. Therefore, informed views lead to the realization that science is a human enterprise practiced in the context of larger *society* and culture.

Teaching NOS is considered a fundamental goal of science education (Kampourakis, 2016; Köseoğlu, Tümay, & Üstun, 2010; Özturk & Kaptan, 2010). Kampourakis (2016) suggests that teaching general aspects of NOS can be a good starting point but more complex aspects should be included and attend simultaneously to multiple contexts. Parallel to Kampourakis, we also suggest that NOS should be taught in challenging contexts such as SSI-based driven courses. Our claim, supported by research that follows, is that an increased understanding of the characteristics of science will lead to an increase in conceptual understanding of scientific concepts, particularly when contextualized in SSI, and will enable students to be more critical of evidence and effectively utilize evidence in the decision-making and debate processes inherent to SSI topics.

Students' understandings of NOS have been examined in numerous studies (e.g., Cil & Cepni, 2016; Köseoğlu, Tümay, & Budak, 2008; Leach, Hind, & Ryder, 2003; Liu & Lederman, 2002; Walker & Zeidler, 2003). Research has consistently shown that typically students have naive understandings of NOS (Khishfe &

Lederman, 2006). A possible explanation for this failure might be due to the underlying assumption that students would learn the nature of science automatically as a result of studying science and engaging in inquiry activities (Abd-El Khalick and Lederman, 2000a). Some reformed-based curricula rely on implicit messages within the curriculum about NOS and assume that students develop NOS conceptions aligned with accepted contemporary views through inquiry-based activities. In contrast, those that advocate explicit approaches argue that improving views of NOS should be deliberately planned for through objectives and specific attention to instructional details during purposeful inquiry investigations. Previous research has suggested that the explicit attention to various aspects of NOS and the emphasis on students' perceptions of NOS are relatively more effective in improving students' and teachers' conceptions of NOS than an implicit approach that relies on the implicit diffusion of NOS concepts though hands-on or inquiry-oriented instruction (Abd-El-Khalick & Lederman, 2000b). Khishfe and Lederman (2006) argued that explicit approach is relatively more effective in improving students' and teachers' understandings of NOS than an implicit approach. However, the explicit approach was not a panacea to produce students "informed" in robust ways about NOS. Much is still desired, as the integration of the explicit approach has met with limited success. This failure is attributed to the context in which NOS has been explicitly taught (Khishfe & Lederman, 2006). Thus, it is important to seek the alternative context for NOS to promote better understandings.

History of science courses in teacher training programs are offered as one kind of authentic context to teach NOS. The literature (Clough, 2011; Klopfer & Cooley, 1963; Matthews, 2012, 2015; Niaz, 2016; Solomon, Duveen, Scot, & McCarthy, 1992) suggests that the history and philosophy of science are 'inside' science content and as such can guide our understanding of NOS. Thus, some science educators advocate for the integration of NOS into the teaching and learning of the history of science. History of science courses cover milestones of science such as development of geometry, optics, physics, medical science, and genetics in general formats. Although the explicit pedagogical aim of these courses is not to make students understand that scientific knowledge is tentative, subjective, theory-laden, etc., teachers can address most of NOS aspects during lectures embedded in the historical development of scientific content knowledge. For example, it is possible to highlight the tentative nature of science while talking about the history of medical science or talking about the life of Hippocrates -- how did he attempt to explain human body, how did he try to find a cure for diseases, how did the medical science knowledge depend on subjective inferences of him? Teaching NOS in such authentic historical contexts rather than presenting it as a list of stereotypic knowledge to be learned can help students to see the processes of science that are derived from human creativity and imagination (Abd-El-Khalick & Lederman, 2000a). Lederman and his research associates argue convincingly (backed by empirical research) that investigating history of science courses in this way will convey to students an appreciation of the values and assumptions inherent to the development of scientific knowledge. Examples from history of science are provided to show how understanding 'science in the making' is important in order to integrate aspects of NOS (Niaz, 2016). Further, Zeidler, Walker, Ackett, and Simmons (2002) suggest that engaging students in socioscientific reflective thinking activities can bring to light the characteristics of science that reflect NOS in yet further comprehensively ways. The next section reinforces this claim and provides research advocating the positon in more detail.

Nature of Science Concepts in the Context of Socioscientific Issues

NOS has been highlighted as a critical component of scientific literacy in recent science education reform (Cakiroglu & Geban, 2010; Kampourakis, 2016; Khishfe, 2012; NRC, 2012; Ryder & Banner, 2011). NOS is certainly a part of what SL entails, as implied by the definition of scientific literacy above. In traditional science classrooms, alternatively, doing science was assumed to be a straightforward, procedural, and value-free activity that was generally disconnected from everyday sociocultural issues. Typically, the conventional teaching of science was aimed at socializing students into a viewpoint whereby students' scientific knowledge and their scientific ways of thinking were supposed to be rational, procedural, and value-free. However, the actual practice of science entails real-life issues that are not so straightforward; they are often messy and contain "unsure things" (Abd-El Khalick, 2003). Actual contextualized science is more complex in real life than the sanitized belief system about decontextualized science propagated in conventional classrooms.

A recent review of literature on SSI and progressive scientific literacy has demonstrated that socioscientific issues provide an ideal context for enhancing students' and teachers' understandings of the nature of science (Zeidler, 2014). Science education researchers have placed an increased emphasis on students developing accurate NOS understanding in SSI contexts (Bell, Matkins, & Gansneder; 2011). Driver, Leach, & Millar, (1996) outlined five areas connected to the moral and ethical aspects of science education that serve as a basis to provide a lasting foundation for emphasizing the importance of understanding sociocultural factors related to the nature of science: utilitarian, democratic, moral, cultural, and science learning. These areas are also central to the SSI-based instruction in multiple ways. For example, a utilitarian perspective of NOS may require managing technological objects and processes in everyday life in ways to better serve more people. The democratic perspective suggests that people should have a fair voice in decision-making procedures about socioscientific issues. The cultural aspect implies that an understanding of science is intricately embedded in contemporary culture. The moral aspect suggests that both individuals and the greater scientific community have an inherent responsibility to consider the ethical ramifications of their decisions and honor moral commitments to create a just world. Lastly, having an intelligent understanding of science is critical, because, in order to make informed decisions about science, one needs to have a clear grasp of science subject matter and know how to evaluate different sources of information. These areas are directly related to the contextualized nature of SSI-based instruction and aim to prepare students in making responsible decisions about meaningful everyday life issues and helping them to become participatory citizens who care about the democratic process and the world in which they dwell (Zeidler, Berkowitz & Bennett, 2014).

Science educators (Khishfe, 2012; Khishfe, & Lederman, 2006; Sadler et al., 2004; Walker, & Zeidler, 2007; Zeidler, et al., 2002) have aimed to identify and explore specific aspects of the relationship between NOS and SSI by addressing NOS components (tentativeness, creativity, subjectivity, theory and law, observation and inference, social, cultural embeddedness, empirical nature of science) in the context of multiple ill-structured problems such as global warming, genetically modified foods, animal rights, and water fluoridation in their research. Findings of this research confirmed that SSI provides an excellent context for explicit NOS instruction by highlighting conflicting evidence, different interpretations of data, and encouraging alternative perspectives of positions as well as solutions to issues.

Teachers' epistemological perspectives and views of NOS are also relevant to meaningful discussions of SSI in science classrooms (Abd-El-Khalick, 2003). Science educators have agreed that teachers' understanding of NOS inescapably changes their pedagogical approach in order to engage students in the activity of science, particularly when it comes to SSI instruction (Sadler et al., 2004; Zeidler, et al., 2002). Therefore, assessing teachers' NOS understanding and application of such understanding in SSI context is important to explore (Abd-El-Khalick, 2003; Bell & Lederman, 2003). Lederman, Antink, and Bartos (2014) conducted a study to examine how teachers can use SSI to teach NOS and address the science subject matter embedded in SSI. Lederman et al., (2014) presented their work as a pathway to developing scientifically literate citizenry. They have addressed how key components of NOS (e.g. tentativeness, creativity, social-embeddedness etc.) may reveal themselves in SSI instruction. However, they issued a caveat that those components should not be considered a comprehensive list, but rather an indicator set of important ideas that are useful for teaching scientific knowledge. Kampourakis (2016) advanced the claim that understanding NOS should have a major impact on argumentation and decision making related to SSI. However, he pointed out that studies on this topic have been inconclusive. While there is not definitive study about the clear impact of understanding NOS on decision making related to SSI, there are several studies (Khishfe, 2012; Zeidler, et al., 2002) that have shown different kinds of nuanced relationships between NOS and SSI.

Lederman et al., (2014) suggested utilizing SSI as a context for facilitating the development of SL and through student reflections on NOS. The researchers' highlighted instances where various SSI (genetically modified foods, genetic testing, stem cell research) could be used to tease out interrelationships of student understanding of science content and aspects of NOS embedded in socioscientific discussions. For example, genetically modified foods (GMO's) were used as examples to show the effects of the sociocultural embeddedness of NOS in controversial discussions. While there is widespread concern across the world regarding the production and consumption of GMO's, the reactions of students from different countries to this issue are quite different. Lederman et al. (2014) compared the labeling requirements of Europe and the US that indicate possible environmental and health risks of the foods with consumer reaction to production and consumption of the foods. While Europe has strict labeling requirements about GMO's, the US does not yet require that products containing genetically modified foods be labeled and much of the public remains relatively unaware of the extent to which these foods are included in their diet. Consequently, people living in Europe are much more opposed to the production of these foods while people who live in the US are much less concerned on the whole. This is clear evidence for *sociocultural embeddedness* of science. While scientific phenomena and related technologies may not vary that much across nations, individual reaction to them certainly does. In addition to sociocultural embeddedness, Lederman et al. (2014) also discussed how scientific knowledge is partially the product of human inference and subjectivity and how personal and political commitments may influence people's decisions on SSI. They pointed out that doctors or genetic counselors' professional training, past experiences, and theoretical and philosophical commitments, affect their inferences while interpreting identical data. These findings further support the utilization of SSI as a context for facilitating students' NOS understandings.

There have been a number of studies that have set out to examine possible explicit connections of how NOS may be realized within the context of SSI. Despite our attempt to rigorously and systematically analyze studies that examine, at least in part, NOS within SSI frameworks, the literature is widely divergent; making sense of it is challenging. As a conceptual literature review, we choose not to include detailed discussions of procedural methodology. However, we do describe below the process for identifying potential papers and selecting those to include or exclude in this review. We summarize studies selected for inclusion to focus more deeply on in Table 1 (below). Studies reviewed in Table 1 were limited to those with strong theoretical frameworks and methods as reflected in their publication by leading international journals of science education.

There are three main reasons for concentrating on these particular studies: 1) selected studies addressed NOS aspects in SSI contexts; 2) participants were at similar grades (secondary or higher); and 3) participants used explicit approaches to teach NOS. These studies span about a decade and are presented in chronological order in Table 1. Excluded, therefore, are studies that were focused on implicit approaches. The rationale for examining explicit approach studies to review is based on the data that has shown it to be relatively effective in school science settings for promoting NOS learning (Akerson, Abd-El-Khalick, & Lederman, 2000). With regard to the studies, the table includes the main NOS concepts embedded within selected SSI topics and the outcomes of the research. We follow this with a short discussion of selected key studies.

Table 1. Nature of science concepts in the context of socioscientific issues

Researchers	Sample	NOS – SSI Contexts	Main findings
Zeidler, Walker, Ackett & Simmons (2002)	11th and 12th grade students (n=147) Upper-level college preservice teachers (n=101)	NOS: tentative, empirical, social embeddedness, creativity SSI: research conducted on animals	• Students' conceptions of the nature of science were reflected in their reasoning on moral and ethical issues. • The reactions of students to anomalous socioscientific data are varied and complex with notable differences in the reasoning processes of high school students compared to college students.
Sadler, Chambers, & Zeidler (2004)	10th grade students (n=84)	NOS: empiricism, tentativeness, social embeddedness SSI: global warming	• Teacher understands the nature of data and its application and uses the term in class, but students may still possess naive ideas about what data is. • Interpretation and evaluation of conflicting evidence in a socioscientific context are influenced by a variety of factors related to NOS such as data interpretation and social interactions including individuals' own articulation of personal beliefs and scientific knowledge.
Khishfe & Lederman (2006)	9th grade students (n=42)	NOS: explicit instruction. (tentative, empirical, creative, subjective, observation-inference) SSI: global warming	• Explicit NOS teaching (regardless of whether NOS was integrated on non-integrated) improved students views of NOS. • Informed views slightly

			increased via integrated and non-integrated NOS approaches, whereas transitional views of the nonintegrated group showed greater improvement. However, the overall results did not provide any conclusive evidence in favor of one approach over the other (integrated vs. non-integrated).
Walker & Zeidler (2007)	9th-12th grade students (n=36)	NOS: tentative, creative, subjective, and social embeddedness SSI: genetically modified foods	• Students utilized more factual-based content of the evidence that ultimately led into numerous instances of fallacious reasoning and personal attacks. •Students were moved beyond developing their NOS conceptions to applying those conceptions within a decision-making context.
Eastwood, Sadler, Zeidler, Lewis, Amiri, & Applebaum (2012)	11th and 12th grade students (n=120)	NOS: subjective, theory-laden, empirical, creative and culturally embedded NOS SSI: stem cell research, euthanasia, fluoridation of public water supplies, safety of marijuana use, fast food, personal and public health	• SSI contexts were effective for promoting gains in students' NOS understanding and suggest that these contexts facilitate nuanced conceptions that should be further explored. • Both SSI and Content groups showed significant gains in most NOS themes, but between-group gains were not significantly different.
Khishfe (2012)	11th grade students (n=219)	NOS: subjective, tentative, empirical SSI: genetically modified food, water fluoridation	• There was a relationship between NOS understandings and argumentation skills in the context of controversial socioscientific issues • The counterargument had the highest correlation, compared to argument and rebuttal, with the emphasized NOS aspects in socioscientific scenarios.
Khishfe (2014)	7th grade students (n=121)	NOS: empirical, tentative, and subjective SSI: water fluoridation, genetically modified food	• There were considerable improvements in participants' understandings of the NOS aspects via explicit approach. •Explicit NOS and argumentation instruction improved the learning of argumentation skills and NOS understandings of participants.

Table 1 provides a succinct overview of research in which NOS has been integrated within the SSI framework. The unifying theme to these studies lies in the investigation of students' conceptions of NOS as they react to SSI. The first study in Table 1 was carried out by Zeidler et al., (2002). The researchers attempted to reveal students' epistemological views of the nature of science and their belief convictions about a selected socioscientific issue. The SSI scenario required students to react to an ethical issue involving research conducted on animals and required them to offer moral lines of reasoning to justify their particular positions. Students were also asked to respond to a NOS questionnaire that aimed to explore students' conceptions relating to the tentative, empirical, social, and creative aspects of NOS. Zeidler et al. (2002) identified only a few discernible instances of a clear relationship. Several selected examples of interest are presented to demonstrate the interplay between NOS views and students' interpretations of ethical issues in science.

Sadler et al. (2004) used the SSI context of global warming. For these researchers, the inclusion of SSI in science classrooms provided opportunities for the development of learning experiences that addressed aspects of NOS. At the same time, the authors indicated that individuals with an informed understanding of NOS would find it very difficult to deny the influence of society on scientific and socioscientific issues. Khishfe and Lederman (2006) conducted their research on the issue of global warming and aimed to address selected NOS aspects (tentative, empirical, creative, subjective, observation-inference) in these studies. For this controversial topic, while students' understanding of NOS improved, no differences were shown between NOS being contextualized within an SSI and NOS being taught alongside scientific content, as long as each approach used an explicit pedagogical techniques.Within the context of genetically modified foods, a SSI approach was used by Walker and Zeidler (2007) and Khishfe (2012) to explore how students' engagement in a learning and debate activity on a current scientific controversy influenced their understanding of the nature of science. In the Walker and Zeidler study, the authors also explored the relationship between students' NOS understandings and their decision-making skills on SSI. Walker and Zeidler (2007) indicated that utilizing current SSI that students found relevant to their lives created an engaging forum for the exploration of NOS aspects alongside discipline-specific science content, as well as to improve their decision-making skills. Khishfe (2012) also confirmed the development of students' NOS understandings in the context of socioscientific issues. Khishfe (2014) updated her previous work that was conducted in 2012, working with 121 seventh grade students. She specifically focused on addressing three NOS components that included empirical, tentative, and subjective factors in the SSI contexts of genetically modified foods and water fluoridation. Results showed improvements in the learning of argumentation skills and NOS understandings of participants in the treatment groups who received explicit NOS and argumentation instruction. The researchers asserted the difference in learners' views were related to some contextual factors such as the familiarity of the content, prior content knowledge, and personal relevance. The author also stressed that if a SSI creates more interest it may better activate more prior knowledge, allowing students to think more deeply about the issue and make meaningful connections to underlying NOS factors.

Eastwood et al. (2012) investigated the effects of two learning contexts for explicit-reflective NOS instruction in an SSI context and rich content-driven classrooms on students' NOS conceptions. The study took place using one exemplary teacher with four classes of grades 11 and 12 students. Two classes experienced SSI-based curriculum and two classes experienced a science content-based curriculum. The study was conducted over an entire academic year. Their results supported the claim that SSI contexts serve as an effective means for promoting gains in students' NOS understanding for the treatment groups over that of the comparison groups. The authors suggested that SSI contexts facilitate nuanced and applied conceptions of NOS.

Discussion

This paper reviewed empirical studies on teaching and learning about NOS which are conceptually framed within SSI contexts in order to find ways to further enrich students' understandings of NOS. Throughout our review, we have shown that there is an interaction between students' views of NOS and response to discourse and exposure to socioscientific issues. Not only an individual's understanding of NOS inevitably alters the manner in which she or he responds to situations involving science, including socioscientific issues, but also SSI contexts alter how students respond/understand NOS.

There are undeniable major challenges embedded in science that confront society such as preventing and treating disease, generating sufficient energy, maintaining food and fresh water supplies, or addressing climate change (NRC, 2012). The Next Generation Science Standards [NGSES], (2012) indicate that any education that focuses solely on the products of science ignores the application of science in real-world issues and overlooks how scientific ideas are socioculturally framed, developed, and implemented, thereby misrepresenting the realistic activity of science. Therefore, it is important for students, as current and future citizens in this technology-rich and scientifically complex world, to see how science is instrumental in addressing major challenges that confront society today. In order to avoid misrepresentations and misunderstandings of both the activity of science, as well as its contributions and limitations, and to provide a deeper understanding about real-world issues, the integration of SSI into science curricula is not only appropriate, but necessary for science education programs to prepare students in the exercise of socioscientific decision-making (Zeidler & Sadler, 2011). Future research may be informed and decisions about the design and implementation of socioscientific curricula as it pertains to NOS integration may be enacted as a result of this focused review.

We cannot overstate the importance of exposing students to SSI in the science classroom, because students will be certain to make decisions about such issues for the rest of their lives. Using SSI approaches taps, as indicated in this review, NOS, cased-based issues, cultural issues, discourse and argumentation skills, and moral as well as general epistemological reasoning. It is difficult, for example, to read a newspaper or watch a newscast without encountering these issues (Sadler et al, 2004). Thus, in order to help students make informed decisions on SSI, teachers will also need to pay attention to global, societal, local, and personally-relevant science issues with obvious societal connections and explicitly discuss the nature of those interactions.

Combining these two constructs by the contextualization of NOS within the SSI framework requires teachers to become informed about guiding students in the process of applying their understanding of NOS as they discuss and evaluate data and take action related to SSI. The studies reviewed here suggest that curricula related to the social, tentative, and empirical aspects of science would be particularly useful for students as they encounter SSI. Sadler et al. (2004) asserted some time ago that researchers need to address how NOS and SSI interact with one another. A continuous line of research reported here helps to guide us in our understanding of those interactions. More recently, Sadler & Zeidler (2009) have argued that serious reform efforts need to be implemented in order to integrate aspects of socioscientific discourse into teacher training programs. Given the corpus of research around NOS and SSI (Zeidler, 2014), we also suggest that teacher training programs should be reformed to include the integration of NOS in the context of SSI. Related positive findings from studies of integrating SSI within a variety of contexts offers additional support for the use of SSI as a curricular vehicle for students' learning of important science content (Sadler, Romine, & Topcu, 2016).

Suggestions for Future Research and Practice

The growing interest in SSI as a vehicle to promote students' NOS understanding in science education precepts intensified research regarding the theoretical basis and practical solutions of these strategies. One of the more obvious recommendations is that the explicit attention to various aspects of NOS and the emphasis on students' perception of NOS is relatively more effective in improving students' and teachers' conceptions of NOS than an implicit approach that utilizes hands-on or inquiry-oriented instruction. This review summarized research findings that revealed that the instruction of NOS in conjunction with discussions about controversial socioscientific issues lead toward achieving scientific literacy. Thus, we recommend for future research to examine how a reflective, explicit approach to teaching NOS can be used along with attention to a relevant socioscientific issue to improve students' understandings of NOS.

Future research should focus on inservice teachers and preservice teachers' NOS understanding within the SSI framework as teachers' understanding of NOS inescapably changes their approach to pedagogy to engage students in the activity of science. Socioscientific issues could provide the classroom teacher with a powerful foundation for discussion of NOS as long as the teacher is knowledgeable about the issues and is skillfull guiding classroom discussions. Thus, we suggest that preservice teachers, as well as inservice teachers become familiar with the theoretical and practical background of using SSI through science courses. Last, future research can use science issues and the history behind them (use of science stories such as the discovery of penicillin, life of Marie Curi, treatment of stomach ulcers, development of stem cell research, or science behind the development of three-parent babies research) as a medium through which NOS could be introduced to students. History of science issues may arouse students' interests, provide an in-depth understanding of what scientists encountered at their time, and promote realizations of the sociocultural effect on science related issues. Addressing NOS concepts in science classrooms should also help students to internalize and comprehend that value-laden decisions are also a part of science. The process of scientific-decisions and socioscientific decisions are not considerably different; in fact, more times than not they are intimately linked. The research seems to point to the fact that students who internalize characteristics of NOS have the propensity to more robustly engage in critical discourse about SSI. In contrast, those do not have informed views are more likely to dismiss such discourse or not back their position with evidence-based reasons. Currently, there is still only modest effort in enhancing classroom-based activities that advocate such discourse relevant to SSI. Developing more informed views of NOS will lead to enhanced classroom discourse about SSI.

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