



**Socio-scientific Issues based Teaching and Learning:
Hydrofracturing as an Illustrative context of a
Framework for Implementation and Research**

**Ensino e Aprendizagem baseado em questões sócio-científicas:
Hidrofraturamento como um contexto ilustrativo de um Quadro
para implementação e pesquisa**

Troy D. Sadler

University of Missouri, Columbia, MO, USA
sadlert@missouri.edu

Christopher D. Murakami

University of Missouri, Columbia, MO, USA
cdmvk7@mail.missouri.edu

Abstract

Global citizens are constantly immersed in issues like hydraulic fracturing or "hydrofracturing" that rely upon scientific knowledge and the ability to negotiate multiple forms of evidence and reasoning to make informed decisions. Historically, Environmental Education and Science Education have been well positioned to provide learning experiences that support the development of important skills like Discourse that are requisite for full participation in our worldwide community. In this article, we explore the confluence of environmental education, science education, and the emergence of an empirical model for socio-scientific Issues (SSI) based teaching and learning. While environmental education and science education have distinct differences, there are significant overlaps in content and process. The emergence of SSI from the field of science education presents opportunities to drive environmental education, and a new framework for guiding SSI based teaching and learning can be useful in terms of informing focus, structure and processes for teaching through issues. Using hydrofracturing as a sample issue, we demonstrate how this recently developed SSI framework can be applied to create learning environments that support

development of critical Discourse practices and further the goals of science and environmental education. The core aspects of the framework are 1) design elements, 2) learner experiences, and 3) teacher attributes. We elaborate each of these aspects and demonstrate how to reposition science content and the roles of students and teachers to engage in the issue of hydrofracturing. The SSI framework also highlights the importance of a safe classroom community and an awareness of the broader geopolitical context when practicing SSI based teaching and learning. This work provides a theoretical and practical basis to drive the fields of science and environmental education towards research and teaching that promote engaged global citizenship and social justice.

Keywords: Discourse; Hydrofracturing; Instructional model; Socio-scientific issues; Theory-to-practice.

Resumo

Cidadãos globais estão constantemente imersos em questões como fraturamento hidráulico ou "hidrofraturamento", as quais dependem do conhecimento científico e da capacidade de negociar múltiplas formas de evidências e de argumentos para tomar decisões informadas. Historicamente, a Educação Ambiental e Educação Científica vêm sendo mais bem colocadas para proporcionar experiências de aprendizagem que suportem o desenvolvimento de habilidades importantes, como o Discurso necessário para a plena participação de nossa comunidade mundial. Neste artigo, vamos explorar a confluência da Educação Ambiental, da Educação em Ciências, e o surgimento de um modelo empírico para o ensino e aprendizagem baseado em questões sócio-científicas (SSI). Enquanto Educação Ambiental e Ensino de Ciências têm diferenças, existem sobreposições significativas no conteúdo e nos processos. O surgimento das questões sócio-científicas vindas da área de Educação Ciência, apresenta oportunidades para conduzir a Educação Ambiental e, também, e um novo quadro, para orientar o ensino e aprendizagem baseado em questões sócio-científicas, que pode ser útil em termos de foco de informação, estrutura e processos para o ensino através de questões. Usando "hidrofraturamento" como um exemplo de questão, demonstramos como esse quadro, recentemente desenvolvido, pode ser aplicado para criar ambientes de aprendizagem que suportem o desenvolvimento de práticas de discurso crítico e promovam os objetivos da ciência e da educação ambiental. Os principais aspectos do quadro são: 1) elementos de design, 2) experiências do aluno, e 3) atributos professor. Elaboramos cada um desses aspectos e demonstramos como reposicionar o conteúdo da ciência e os papéis de alunos e professores para o engajamento na questão do "hidrofraturamento". Neste quadro destaca-se a importância da sala de aula como uma comunidade segura e de uma consciência do contexto geopolítico mais amplo quando se pratica o ensino e aprendizagem baseado em questões sócio-científicas. Este trabalho fornece uma base teórica e prática para conduzir os campos da ciência e da educação ambiental no sentido de uma pesquisa e um ensino que promovam a cidadania global engajada e justiça social.

Palavras-chave: Discurso; hidrofraturamento; Modelo instrucional; Questões sócio-científicas; Teoria e prática.

Environmental Education, Science Education & Socio-scientific Issues

Historically, the fields of environmental education and science education have shared a natural linkage (HART, 2007, p.689). Environmental issues tend to have bases rooted in science, and science fields such as ecology, conservation biology, environmental geology, and green chemistry devote primary attention to issues of environmental concern. Of course, the two fields also have unique aspects in terms of both content and focus. The relationship can be represented by a simple Venn diagram, in which each field is represented by a circle, and the circles overlap. Socio-scientific issue (SSI) based teaching and learning is a movement that has emerged within the field of science education with the aim of promoting student engagement with science that matters beyond classroom walls. Individuals in modern societies confront a constant barrage of social challenges that relate substantively to science ideas and processes. Citizens in today's world face SSI as they make consumer choices (e.g., to buy genetically modified foods), health-care decisions (e.g., to vaccinate children), voter choices (e.g., to cast a vote for a politician who denies climate change), and community decision-making (e.g., to advocate for or oppose the installation of a wind farm). A central aim associated with SSI based teaching and learning is to facilitate student exploration of SSI such that they become better prepared to negotiate SSI more generally (ZEIDLER; SADLER, 2008, p.799).

As the preceding discussion suggests, SSI may vary in focus across a wide range of topics, many of which would be classified as environmental issues (KLOSTERMAN et al., 2011, p.51). Thinking back to the Venn diagram suggested above to represent the relationship between environmental and science education, SSI could be added such that it spans the area of overlap and other aspects of science education (see Figure 1). Classroom based projects that focus on global issues such as climate change (FEIERABEND; EILKS, 2010, p.176) and local issues such as a community's pollution problem (EVAGOROU, 2011, p.133) provide examples of SSI well aligned with an environmental education focus. The use of cloning for therapeutic purposes is a SSI that likely sits within the non-overlap science education area. More important than this simple representation of the relationships among science education, environmental education and SSI based teaching and learning is the attention this special issue calls to the position of different discourses within these areas and ways in which environmental and science education contribute to democracy, citizenship, and social justice. Most of what actually happens in formal science education has very little to do with supporting learner participation in democracy, engagement in citizenship, or exploration and pursuit of social justice. Achieving these ends is central to the foundation of what has become the SSI movement (KOLSTØ, 2001), and engaging learners in meaningful discourse in issues of environmental and other social concerns is a primary vehicle for the pursuit of these aims.

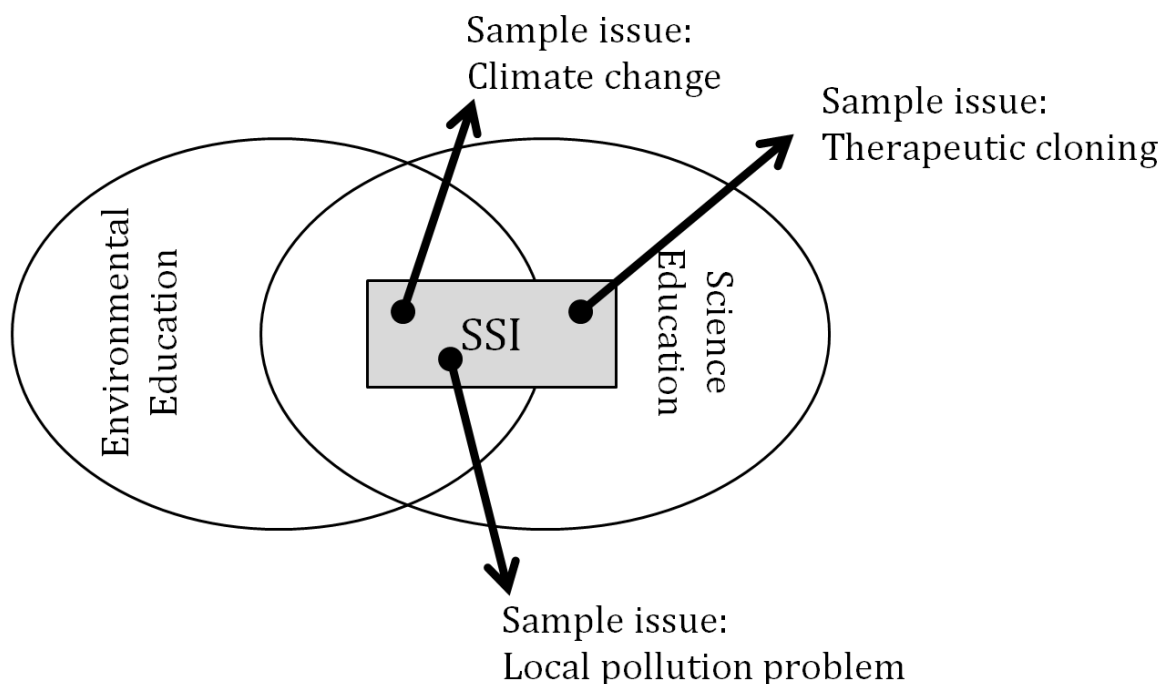


Figure 1: A graphic depiction of the relationship between environmental education, science education and socio-scientific issues based teaching.

Goals for Science & Environmental Education

In a review paper linking SSI and situated learning theory (SADLER, 2009a, p.1), I argued that a, if not *the*, primary purpose of science education, and SSI based teaching and learning in particular, should be for:

[...] learners to come to identify themselves as willing and able to engage in socio-scientific Discourses. As such, learners come to position themselves as active contributors to society with competencies and willingness to employ scientific ideas and processes, understandings about science and social knowledge (e.g., ideas about economic and ethical influences) to issues and problems that affect their lives. The goal is for learners to develop a sense of having something to say about these issues and to see themselves as legitimate participants in social dialogues, particularly those which involve science. (SADLER, 2009a, pp. 12-13)

Here, the notion of Discourse is based on Gee's (1999, p.7) ideas which highlight Discourse (capital D) as encompassing spoken and written expression (lower case d discourse) along with a broader range of community-specific activities and social norms. Discourse and identity are necessarily interrelated in that a learner's identity shapes the Discourses she enacts and the Discourses in which one engages influence the identities she constructs.

Promoting these kinds of Discourses and identities represents a laudable goal for science (and environmental) education, but achieving these ambitious ends is certainly not a simple matter. In fact, the SSI movement emerged in response to science-technology-society (STS) initiatives that failed to achieve significant

democratic and citizenship aims (ZEIDLER et al., 2002, p.343). STS approaches gained popularity and widespread application in the 1980s and 90s and, like SSI, attempted to link science learning with social and environmental issues. However, STS has been criticized for becoming too broad, lacking a focus and framework (ZEIDLER et al., 2005, p.357). Although far more modest than STS, the SSI movement has begun to generate global attention, and for the most part, the movement has maintained a common focus and vision consistent with the goals articulated above. However, if this focus is to be maintained (and SSI is to avoid the diluted fate of STS) as SSI based teaching and learning spreads to broader communities of researchers, curriculum designers, and practitioners, more focused tools are necessary for guiding this work. A conceptual framework that identifies the theoretical and empirical underpinnings of SSI based teaching and learning has been presented and has evolved given new research and theoretical insights (ZEIDLER et al., 2005, p.357). Exemplar SSI-based learning experiences including individual lessons, comprehensive units, and year-long courses have been shared (e.g. SLESNICK, 2004). New assessments designed to capture dynamic aspects of learning associated with SSI have been advanced (SADLER; ZEIDLER, 2009, p.909); although, work in this area remains far from complete. An important area of need that still remains is a tool to help translate the vision for SSI based teaching and learning from the realm of research and theory to the domain of practice.

A recently published edited volume (SADLER, 2011), highlighted nine SSI research projects all of which were based on empirical investigations of SSIs enacted within classrooms. The projects were situated in multiple international contexts (in Asia, Australia, Europe, North America, and the Middle East), covered diverse issue contexts (including local environmental challenges, biotechnology issues, air pollution, and genetic engineering), and worked with a range of student populations (from elementary grades to college undergraduates). By looking across these projects and analyzing elements from each with empirical supports for their efficacy, it became possible to generate a model for SSI based teaching and learning. This is precisely the kind of tool needed to help translate the SSI agenda from research to practice. An initial version of this framework was presented in the edited volume (Sadler, 2011, p.353) and expanded in a recent article (PRESLEY et al., 2013, p.26). In the current paper, we offer an elaborated version of the framework with a key environmental issue offered as a context.

Over the last decade, climate change has been the dominant global environmental issue. As we look forward, environmental scholars predict that issues associated with quality of and access to fresh water will continue to rise in scope, prominence and significance (ARNELL, 2004, p.31). Hydraulic fracturing, also referred to as “hydrofracturing” or “fracking,” is an issue that sits at the intersection of climate change and water quality and availability. Hydrofracturing is a method of extracting oil and natural gas from shale deposits. It is controversial because while the technology enables access to previously inaccessible energy sources, there are numerous environmental concerns associated with it. Advocates such as international energy corporations and some governmental agencies (e.g. the United States Environmental Protection Agency) cite the potential of hydrofracturing to support economic growth, to increase energy availability, and to mitigate against climate change. Opponents such

as environmental groups and other governmental organizations (e.g. the European Parliament's Environment Committee) cite concerns related to contamination of ground water, removal of large quantities of water from natural cycling processes, and compounding problems associated with climate change. Hydrofracturing is a widespread issue in the United States, and energy companies are looking worldwide for expansion opportunities. With one of the world's largest reserves of shale gas, Brazil is already witnessing intense debate regarding the use this technology (see KEMP, 2012; STEFANINI, 2013). Given the temporal and geographic significance of hydrofracturing, we use it as an issue context to describe the SSI framework introduced above. The next section provides additional details about hydrofracturing, and then we use the issue to illustrate elements of the SSI framework.

Hydraulic Fracturing

Hydrofracturing is a method of extracting oil and natural gas trapped in the previously inaccessible shale deposits. After wells are drilled vertically and then horizontally with depths of up to 3,000 meters, they are fortified with steel and cement to help prevent contamination of ground water. Large volumes of water, sand, and extraction chemicals are shot into these wells at high pressures to create fissures in the shale and help release the natural gas and oil. The wells are then equipped with condensers to economically capture and separate the fossil fuels from the wastewater. Depending on the wells, somewhere between 15-85% of the wastewater is recovered and recycled for further use in extraction, the rest is left in the capped wells or deposited in underground disposal sites, permanently removing the water from the hydrological cycle (ENVIRONMENTAL PROTECTION AGENCY, 2010).

While hydrofracturing is not new (there are records of the technology dating back to the 1940s), it has proliferated in the past ten years in the US and has begun in Poland, South Africa, and China with the potential to spread to South America. Currently, hydrofracturing has been outlawed in the European Union, because of concerns of surface and groundwater contamination from the chemicals used in the extraction process and the unknown long-term effects. However, in countries like the US, hydrofracturing has produced a glut of natural gas that is part of a plan for national energy independence and new job creation.

Proponents argue that the technology leads to climate change mitigation because natural gas releases significantly less CO₂ than other fossil fuel based energy sources (EIA, 2013). However, in addition to the potential for significant water pollutions and disruptions to the natural hydrological cycle, critics are concerned that methane leaks during extraction and/or post-production would more than offset any greenhouse gas improvements.

A Framework for SSI Based Teaching & Learning

Core Aspects

Our purpose here is to present a framework for SSI based teaching and learning and to present the framework using the hydrofracturing issue. A graphic depiction of the framework is presented in Figure 2. Three *core aspects* of SSI based teaching and learning are positioned centrally within the framework. These core aspects are 1) design elements, 2) learner experiences, and 3) teacher attributes. Design elements correspond to features of curricular design necessary for SSI teaching and learning and they include the following: a) building instruction around a compelling issue, b) presenting the issue first, c) providing scaffolding for higher-order practices, d) providing a culminating experience, e) using media to connect classroom activities to representations of the issue beyond the classroom, and f) using technology to facilitate student learning experiences.

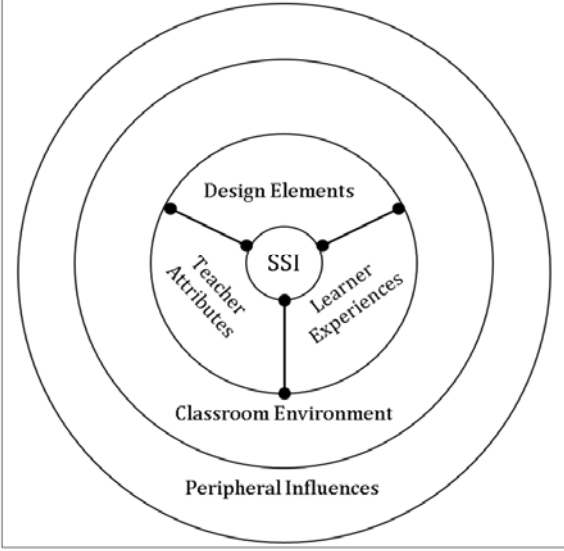
| Graphic representation of the framework | Core Aspects |
|--|---|
|  | <p>1. Design Elements</p> <ul style="list-style-type: none"> a. Building instruction around a compelling issue. b. Presenting the issue first. c. Providing scaffolding for higher-order practices. d. Providing a culminating experience. e. Using media to connect classroom activities to the “real world.” f. Using technology to facilitate student learning experiences. |
| | <p>2. Learner Experiences</p> <ul style="list-style-type: none"> a. Engaging in higher-order practices. b. Confronting scientific ideas and theories related to the issue. c. Collecting and/or analyzing scientific data related to the issue. d. Negotiating social dimensions of the issue. e. Confronting the ethical dimensions of the issue. f. Considering nature of science themes associated with the issue. |
| | <p>3. Teacher attributes</p> <ul style="list-style-type: none"> a. Knowledgeable about the science content related to the issue. b. Aware of the social considerations associated with the issue. c. Honest about knowledge limitations. d. Willing to position self as a knowledge contributor rather than sole authority. |

Figure 2. Framework for SSI based teaching and learning.

A SSI learning experience related to hydrofracturing should use the issue context as the primary driver of the curriculum. In other words hydrofracturing should serve as a curricular anchor for the design and implementation of the learning experiences. Therefore, the issue or a case illustrating the issue would serve as the learners' entry point to the unit (as opposed to using the issue at the end of a unit dominated by discussions of science content as an example of how that content may be applied). SSI learning experiences should provide opportunities for students to engage in critical thinking, decision-making, argumentation and/or other higher-order practices, but we know that learners of all ages struggle to engage in advanced forms of these practices. In order to effectively support student growth in these areas, SSI learning experiences should scaffold student engagement in these practices. For example, instructors, curricular materials and/or learning technologies could be used to help students connect diverse claims regarding the potential benefits and challenges associated with hydrofracturing with specific pieces of evidence derived from investigations of

hydrofracturing cases. The framework also suggests that students be provided with opportunities to synthesize their experiences and understandings of the issue in a culminating activity. This synthesis activity could take many forms; in the case of hydrofracturing, students could create a public service announcement regarding potential dangers of the technology, draft policy recommendations for a governmental agency considering regulation decisions regarding the practice, or stage a debate on the potential impact of hydrofracturing on energy and climate change. The final two design elements (using media and technology) represent implementation suggestions more than absolute design requirements. For hydrofracturing, diverse media sources (e.g., print news, Internet reports and opinion, and films) present a wide range of information on the general topic, aspects of the controversy and specific cases. These can be used as rich sources for information and resources for students to explore. Likewise, technology can be used in a variety of ways to support student inquiry into hydrofracturing including basic access to some of the media just highlighted, communication with issue experts and/or advocates, and access to and analysis of case-related data sets.

Learner experiences are positioned as the second core aspect of the framework. Learner experiences highlight the kinds of things students should have opportunities to do in the course of SSI based teaching and learning. These experiences, which are necessarily linked with the design elements include a) engaging in higher-order practices, b) confronting scientific ideas and theories related to the issue, c) collecting and/or analyzing scientific data related to the issue, d) negotiating social dimensions of the issue, e) confronting the ethical dimensions of the issue and f) considering nature of science themes associated with the issue. In a hydrofracturing-based SSI learning experience, learners should have opportunities to engage in scientific argumentation and/or some forms of decision-making regarding the issue. In other words, the experience should do more than simply describe the process of hydrofracturing, but rather offer opportunities to engage in deep thinking about the issue. The framework suggests that students should negotiate substantive science associated with the issue and deal with relevant scientific data. Students exploring hydrofracturing could consider issues associated with renewable versus non-renewable resources and resource cycling. Analyzing data associated with the quantity of water used in a hydrofracturing site, concentrations of pollutants such as benzene and methane in wastewater, and the proportion of water that can be reused would be valuable exercises as students consider relationships between hydrofracturing, the water cycle, and human use of water resources.

In addition to a focus on the science of hydrofracturing, students should also have opportunities to explore some of the issue's social dimensions. Hydrofracturing presents interesting challenges that pit energy and economic interests at odds with management of natural resources. Issues associated with who has a right to use and possibly pollute water resources as well as extract and profit from energy sources offer ethical questions that can help support students' development of progressive forms of scientific literacy (SADLER; ZEIDLER, 2009, p.909). Finally, SSIs typically have multiple connections to ideas about how science is done and the nature of scientific knowledge. Notions of proof, certainty and the associated role of data are significant issues in the interpretation of reports offered by various hydrofracturing stakeholders. For instance,

energy companies argue that the absence of incontrovertible proof of a link between hydrofracturing and environmental problems provides justification for further application of the technology. This offers an example of how science can be used to externalize environmental cost and how power (political and economic) can heavily influence knowledge.

Teacher attributes constitute the final core element. In order to successfully implement SSI based teaching and learning, teachers need to be a) knowledgeable about the science content related to the issues, b) aware of social considerations associated with the issue, c) honest about their own knowledge limitations, and d) willing to position themselves as knowledge contributors and not necessarily the sole authority within their classrooms. Teaching science and environmental education in the context of hydrofracturing requires a degree of teacher expertise regarding the underlying science. There are dimensions of earth science (e.g. the water cycle and characteristics of shale) and chemistry (e.g. the nature of solutions and toxicity of benzene) that teachers need to understand in order to guide student explorations of hydrofracturing. Teachers also need to have an awareness of some of the social issues embedded within the hydrofracturing debate. It would be unrealistic to expect teachers to have expertise regarding all of the numerous social and ethical issues associated with hydrofracturing, but they do need to have an awareness of some of these issues as a means of creating opportunities for and responding to student negotiations of some of these issues. Furthermore, the framework suggests that teachers be open about the fact that they do not have all the answers or even know all of the information pertinent to hydrofracturing. The fact is that no one has all the answers and this is an important dimension of the issue. Truly successful SSI based teaching and learning requires that both students and teachers contribute to knowledge and solution generation. For some teachers, this positioning as a collaborator within a classroom community may be quite different than the more traditional role as the classroom authority, but distributing authority across the classroom can have very significant implications for the kinds of Discourses that can emerge.

Classroom Environment & More Peripheral Influences

The classroom environment is a second layer of the SSI framework (see Figure 2) and represents ways in which the classroom environment defines and influences enactment of the core aspects. The classroom environment will afford and constrain ways in which teachers and students interact, expectations for the classroom community, and ultimately what is possible to achieve through SSI based teaching and learning. Dimensions of the classroom environment that have been shown to support successful implementation of SSI include a collaborative and interactive atmosphere, a community in which all participants (teachers and students) demonstrate respect for one another and their perspectives (even when those perspectives diverge), and high expectations for participation and performance.

The classroom represents the first of many nested contexts that will necessarily shape SSI based teaching and learning. The school environment, the local community, along with state and national contexts will significantly influence ways in which SSI can be featured in classrooms. A hydrofracturing unit implemented in Pavilion, Wyoming, a

US community that has been struggling with the impacts of hydrofracturing since 2008, will be received differently than a community in the Paraíba Valley, Brazil, where hydrofracturing may soon be used. In addition to local history and current events, issues such as state and national standards and expectations for science and environmental education will carry important implications for what can and cannot be accomplished through SSI based teaching and learning.

Conclusions

Employing a SSI based teaching and learning approach offers a natural bridge between science and environmental education particularly when the intended goals include engaging learners in Discourses that support their contributions to democratic engagement, participatory citizenship and social justice. However, a significant challenge in achieving the enactment of SSI based teaching and learning is the availability of tools that can inform advancement of a coherent SSI research agenda, development of SSI oriented curricula and materials, and implementation of SSI learning experiences (SADLER, 2009b, p.697). In this article we present a framework to help meet this need, and we elaborate on aspects of the framework through references to how the issue of hydrofracturing could be used as an issue context. Three core aspects including design elements, learner experiences, and teacher attributes in addition to the classroom environment and more peripheral influences comprise the SSI framework. Constitutive aspects of the hydrofracturing issue such as significant connections to fundamental concepts and principles in earth science and chemistry; necessary links between economics, politics and ethics; and inevitable tensions between energy availability, protection of natural resources, implications for climate change and access to fresh water make the issue an ideal context for demonstrating the SSI approach. Our intent is that this contextualized description of a framework for SSI based teaching and learning can spur new developments and innovation in the use and investigation of SSI in support of science and environmental education.

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