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Socioscientific Issues: A Path Towards Advanced ScientificLiteracy and Improved Conceptual Understanding of Socially Controversial Scientific Theories

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Socioscientific Issues: A Path Towards Advanced Scientific Literacy and Improved Conceptual Understanding of Socially Controversial Scientific Theories

by

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Abstract

This thesis investigates the use of socioscientific issues (SSI) in the high school science classroom as an introduction to argumentation and socioscientific reasoning, with the goal of improving students' scientific literacy (SL). Current research is reviewed that supports the likelihood of students developing a greater conceptual understanding of scientific theories as well as a deeper understanding of the nature of science (NOS), through participation in informal and formal forms of argumentation in the context of SSI. Significant gains in such understanding may improve a student's ability to recognize the rigor, legitimacy, and veracity of scientific claims and better discern science from pseudoscience. Furthermore, students that participate in significant SSI instruction by negotiating a range of science-related social issues can make significant gains in content knowledge and develop the life-long skills of argumentation and evidence-based reasoning, goals not possible in traditional lecture-based science instruction. SSI-based instruction may therefore help students become responsible citizens. This synthesis also suggests that that the improvements in science literacy and NOS understanding that develop from sustained engagement in SSI-based instruction will better prepare students to examine and scrutinize socially controversial scientific theories (i.e., evolution, global warming, and the Big Bang).

Introduction

A growing body of research in science education has been highlighting the role of socioscientific issues in improving nature of science (NOS) understanding (e.g., Khishfe & Lederman, 2006; Lewis, Amiri, & Sadler, 2006; Sadler, 2004; Sadler, Chambers, & Zeidler, 2004), scientific literacy (SL) (e.g., Sadler, 2011a; Zeidler & Sadler, 2011), and socioscientific reasoning (SSR) (e.g., Sadler, Barab, & Scott, 2007; Sadler, Klosterman, & Tpocu, 2011; Zeidler & Sadler, 2011) while simultaneously addressing science content (e.g., Applebaum, Barker, & Pinzino, 2006; Kolstø, 2001; Sadler, 2009; Sadler & Fowler, 2006). A wide range of literature corroborates the socioscientific issues (SSI) framework as an effective teaching pedagogy that promotes goals associated with SL as well as citizenship education and students' moral character development (Driver, Newton, & Osborne, 2000; Sadler, 2009; Zeidler & Keefer, 2003).The skills associated with functional SL, such as scientific reasoning, problem solving, evaluating evidence, and rational skepticism are also considered among the goals of citizenship education (Ryder, 2001). Zeidler, Sadler, Simmons, and Howes (2005) detail a progressive view of SL that include students developing an understanding of the epistemology of scientific knowledge and the processes which define science as way of knowing, uniquely separate from faith or acceptance on authority. They contend that this understanding and awareness prepares the student to make informed decisions on scientifically based personal and societal matters where careful analysis of science claims "by discerning connections among evidence, inferences, and conclusions" (Zeidler et al., 2005, p.358) are made possible. Thus, a student's level of SL then becomes more "functional" and therefore, more useful in their day-to-day lives. Such skills and abilities are thought to be essential for students to effectively negotiate and scrutinize the many scientific claims they will inevitably encounter in public media (Dawson & Venville, 2009; Osborne, Erduran, & Simon, 2004; Zeidler, Osborne, Erduran, Simon, & Monk, 2003). The purpose of this paper is to conceptually extend the potential benefits of SSI pedagogy beyond what has already been demonstrated in the literature (e.g., Sadler, 2004; Sadler et al., 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009), by examining how exposure to SSI and the corresponding classroom experiences can inform and influence students' analysis of socially controversial theories (e.g., evolution, climate change, and the Big Bang) – topics that have remained remarkably challenging to scrutinize for many students (Hildebrand, Bilica, & Capps, 2006).

SSI can positively influence how students approach and understand socially controversial theories by cultivating argumentation skills and providing a platform to engage in creating, evaluating, and defending arguments (Zohar & Nemet, 2002). The proposed result of engaging in such SSI discourse include improvements of students' SSR as well as their SL (Zeidler & Sadler, 2011). The purpose of this paper is to address and flesh out those topics and add support to the claim that utilizing SSR in an SSI framework can provide the means for students to examine scientific theories from a more evidence-based perspective, both in and out of the classroom. Examining the justification and goals associated with SL at the onset of this paper provides the initial support for implementing the SSI pedagogy in achieving SL among a diverse student body. Since the nature of science (NOS) is considered to be inexorably linked to SL, a brief discussion of NOS will follow and further demonstrate how SSI pedagogy can promote improved NOS awareness. The SSI teaching framework is introduced with relevant research to reaffirm SSI's capability of realizing goals and securing skills associated with SL as well as a deeper conceptual understanding of scientific theories. The teaching framework of argumentation, considered complimentary to SSI will provide additional research-based support for using SSI to increase student conceptual understanding while nurturing their appreciation of evidence-based reasoning. Socially controversial issues are then presented to showcase what makes these topics so uniquely challenging to teach and what sort of factors come to bear on students' efforts in scrutinizing these theories. In conclusion, this paper will make the case that SSI-based instruction is the most appropriate pedagogy for advancing student's conceptual understanding of these socially controversial issues.

Scientific Literacy

The terms scientific literacy and science literacy have historically been used interchangeably and are referred herein as SL without any concern of misrepresenting the meaning (Roberts, 2007). However, the broadness and scope present in the literature defining such a concept is another matter and has made SL increasingly more difficult to operationalize (Deboer, 2000; Roth & Barton, 2004). Recent definitions of SL go well beyond the historical meaning that was once thought to simply represent what students ought to know about science. The fast growing demands of society and the workplace require the meaning of SL to include an ever greater scope of abilities relative to science and technology. For example, Aikenhead (2006) describes SL as the ability to understand media accounts of science and be able to use such science in decision making on SSI as well as everyday issues. With a greater emphasis on science and technology in science education as supported by the National Science Education Standards (NSES) (National Research Council (NRC), 1996) and continued federal funding, the meaning of SL has evolved to include an array of abilities, skills, knowledge, and agility of scientific affairs (Roberts, 2007). Unfortunately, a proliferation of many misguided and unfounded strategies and methodologies was also able to hitch a ride on SL’s popularity (Shamos, 1995). The mere mention of SL provoked nobility and sincerity to whatever the particular cause or reform proposed, however dire the consequences or misguided the efforts, and has left SL with a convoluted history and indistinct future (Deboer, 2000).

Broadly conceptualizing SL can actually be of help to science education insomuch as it allows some flexibility when used as a rationale to address the needs of our society as they progress and transform. Laugksch (2000) defines SL in hierarchical order of what the SL person should be able to do, such as: understand the nature of scientific knowledge; accurately apply appropriate science concepts and principles; and use science in solving problems and making decisions. Simplifying the examples above into two distinct visions, Roberts (2007) describes SL in terms of practicality and functionality. More specifically, Vision I references the practical aspect of scientific knowledge such as its principles and tenets, while Vision II highlights the functionality of that knowledge and "derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter a citizens" (Roberts, 2007, p. 730).

Faced with the new obligations of preparing students for an ever changing and competitive workforce, the science education community recognizes SL not only as a desirable student outcome but as an outcome essential to a student's success as a responsible citizen (Aikenhead, 2006). Yet there appears to be a disingenuous effort toward any significant SL education and consequently, students are not likely to graduate having a basic understanding of the ways science and technology impact and influence one another (Mooney & Kirshenbaum, 2009). As a result, Hodson (2003) cautions that, students in a "physical and sociopolitical environment will be effectively disempowered and susceptible to being seriously misled in exercising their rights within a democratic, technologically-dependent society" (p.374). Securing more opportunities for SL education that emphasizes Vision II seems most appropriate in safeguarding those rights.

For example, students proficient in Vision II are expected not only to have a functional understanding of scientific concepts but also possess the ability to utilize this knowledge when making decisions about personal and societal matters (Roberts, 2007). Vision II of SL encompasses the cognitive and socio-cultural perspectives influencing what Zeidler et al. (2005) describes as functional SL and more importantly, claimed was attainable with SSI.

The Nature of Science

Introducing the nature of science (NOS) and its instruction will be helpful in elucidating not only the need for understanding NOS, but also the influence that understanding has on the individual negotiating SSI or examining scientific theories. Descriptions of SL have historically included NOS concepts to detail specific attributes of science that define its unique epistemology. NOS represents a multifaceted concept that is also similar to previous discussions of SL insofar as it eludes a simple definition, regardless of its long history in education. Originally compiled by science educators to best characterize the scientific enterprise, NOS conveys to the layperson what it means to do science. Understanding NOS provides a clearer view of what science is, what it can do, its limits and strengths, and how it differs from other disciplines (Khishfe & Lederman, 2006). Student understanding of NOS has been a major goal of national standards and benchmarks (American Association for the Advancement of Science (AAAS), 1989, 1993; NRC, 1996, 2000) in secondary education for decades. NOS can be described in terms of values and assumptions fundamental to the development of scientific knowledge (Sadler & Zeidler, 2004b). Bell and Lederman (2003) characterize NOS as the epistemology of science responsible for one of the three domains of science critical in developing SL: the first domain being the body of knowledge; the second, its methods and procedures; and lastly, it represents science as a unique way of knowing.

There is no universal conceptualization of NOS, however, there is a general consensus that NOS refers to the assumptions, values, and characteristics of scientific knowledge (Aikenhead, 2006; Sadler & Zeidler, 2004b). Given the multifaceted and complex nature of the science endeavor to produce knowledge, certain features comes to typify the manner in which science is practiced (Lederman, 2007). What follows is not intended to be an exhaustive list of the conceptualizations of NOS; however for purposes of this paper, it does highlight areas that engagement in SSI can explicitly address. Science is a human endeavor complete with fallibility and inherent limits; science has a tentative nature subject to change upon new discoveries or evidence where claims are never proven only falsified; science has its foundation on empirical observation of the natural world; these observations are theory-laden, subjective, and involve human inferences; science utilizes imagination and creativity in advancing new ideas and explanations; and finally, science has social and cultural influences embedded in it. It can be argued that from discursive activities such as defending claims, offering rebuttals, and developing criteria for evidence evaluation, students are exposed, engaged, and well-practiced with most, if not all, the tenets of NOS even during just a single SSI activity. Involvement in SSI type activities throughout a particular science course affords ample opportunity for explicitly addressing the tenets of NOS in authentic and relevant scenarios while providing more time for students to assimilate and understand it (Ryder, 2001).

After decades of research on NOS, Lederman (2007) identified some generalizations of NOS that are helpful in better understanding the current climate of NOS education and assist in ways of improving it. He found neither teachers nor students typically possess adequate conceptions of NOS, and regardless of whether teachers did have a sufficient understanding, they felt NOS education was not important enough to supersede teaching traditional subject matter. With respect to teaching the characteristics of NOS, Bell and Lederman (2003) emphasize the need to make those tenets explicit to students if any significant understanding is to be achieved. Lederman (2007) argues that conceptions of NOS are not necessarily or automatically transmitted to students passively, irrespective of the time and type of involvement in inquiry. Khishfe and Lederman (2006) discovered that integrating NOS instruction contextually within SSI, as opposed to simply explicating the various tenets out of context, did not appear to influence students' understanding of NOS. Lewis et al. (2006), however, did report improvements in NOS understanding after a year-long involvement of SSI in anatomy and physiology classes. Other investigators have documented similar gains in NOS understanding from sustained involvement of SSI throughout the course (e.g., Laius & Rannikmae, 2011; Kolstø, 2001; Sadler et al., 2004; Sadler & Zeidler, 2004b; Zeidler, Walker, Ackett, & Simmons, 2002). Despite their original findings, Khishfe and Lederman (2006, p. 415) advocate using SSI to "bring students into direct contact with the values and assumptions, and concepts embodying NOS" and "provide an ideal context for promoting students' understandings of NOS". Explicitly covering the views of NOS leads to greater understanding of the conceptualizations of NOS, and supports the contention that it can be effectively taught through negotiations with SSI, provided they are identified as they arise.

SSI engages learners in epistemic practices similar to how real science is done, whereby the selection of evidence for the construction of explanations matters. Through practice and development of what counts as quality evidence, students can develop criterion to better differentiate pseudoscience from science (Kolstø, Bungum, Arnesen, Isnes, Kristensen, Mathiassen, Mestad, Quale, Tonning, & Ulvik, 2006) while becoming better informed and more responsible citizens (Duschl, 2007). It is therefore imperative for students to have the opportunity to learn "how we know what we know and why we choose to believe it over alternatives" (Duschl, 2007, p.163). Recent studies suggest increased NOS awareness can improve students' ability to understand scientific issues and make more informed and reasoned decisions when negotiating SSI (Liu, Lin, & Tsai, 2011; Wu & Tsai, 2011). The extension of these outcomes is self-evident. Those students with advanced NOS understanding could more critically and rationally analyze the evidence and principles associated with socially controversial theories. Likewise, Liu et al. (2011) found students whose views concurred with the conceptualizations of NOS, were more likely to dismiss or question omniscient authority and recognize the complexity and multiple perspectives inherent in SSI. From the vantage of an informed and rational skeptic, students can make progress toward recognizing and eschewing pseudo-scientific alternatives, extraordinary non-scientific claims, and general misrepresentations (Zeidler et al., 2005), inexorable characteristics typical of socially controversial theories.

Socioscientific Issues

SSI inspire, provoke, or otherwise insight controversy. Such issues are often found among frontier science (science in the making) potentially regarding animal, energy, and land usage, and genetic and reproductive technologies. They typically involve expert disagreement on central scientific questions that lack simple and clear solutions (Kolstø et al., 2006). This sort of controversy that incites student engagement may be unique to SSI since it is unlikely such provocation could emerge in lecture-based classrooms. The justification for using SSI, explains Zeidler et al. (2009), is established in the theoretical framework from areas of developmental psychology, sociology, and philosophy. A teaching framework developed for teachers by Levinson (2006) articulates three strands of importance when considering topics of interest: reasonable disagreement; the communicative virtues; and modes of thought. When describing controversial issues, he identifies three common characteristics to include: 1) people from different premises holding different key beliefs, understandings, values, or conflicting explanations or solutions; 2) substantial number of people or groups; and 3) the issue is not capable of being settled by appeal to evidence.

According to Kolstø et al. (2006), there are two main questions that must also confront SSI participants. One is the ethical, personal, or social question concerning what preference or particular action to take. The second is in regard to the science question involved or the supposed risk to health or environment as informed by the science. There are four distinct areas critical to the teaching of SSI according to Zeidler et al. (2005) that encompass a conceptual model of SSI education: NOS issues; discursive activities; cultural issues; and case-based issues. Together, these areas serve as entry points to authentic and relevant scenarios or case studies to be investigated and argued by the students (Zeidler et al., 2005).

Without attending to moral judgments provoked from the particular social dilemma, however, students will have difficulty finding the science behind these issues real or meaningful (Zeidler et al., 2005). “Separating learning of the content from consideration of its application and its implications (i.e., context) is an artificial divorce” (Zeidler & Sadler, 2008, p.201). In a seminal paper, Zeidler et al. (2005) judiciously usurped the science and technology society (STS) construct with SSI in order to include in the teaching construct, these vital components of character development and to define socioscientific issues as those capable of courting moral considerations. The more controversial an issue, the greater the reliance on moral and ethical deliberations becomes as well as a more distilled view of ones’ own moral limits (Zeidler & Keffer, 2003). Moreover, Zeidler (2007) argues that without the moral component, elements of virtue, and ethical reflections required of SSI, students fail to meet the holistic construct of functional SL previously discussed as Roberts’ (2007) Vision II.

The questionable nature of possible resolutions, given the complexities in thoughtful controversy, can force students to consider solutions from many different perspectives as well as from many different areas of interest before making final decisions (Zeidler et al., 2002). These final resolutions are often in stark contrast to students’ initial, more emotive response to a given scenario (Sadler & Zeidler, 2005). A much more considerate and confident student seems more to emerge from the practice and negotiation of several different SSI units interspersed throughout the course. In such a study, Zohar and Nemet (2002) documented students' progress in presumptive reasoning and development of epistemic criteria used in evaluating evidence after a 12-week argumentation intervention pertaining to genetics. In search of resolutions, they discovered students employ many resources and pull together many views, typically (necessarily) in conflict with one another. However, if performed without reflections on moral grounds concerning the course of action, Zeidler and Sadler (2008) argue that the science is no longer authentic or meaningful, and engagement will suffer. It would seem learning in the context of SSI needs to become personal to ensure the science content and its applications become relevant and important enough for students to allocate the necessary effort to actively participate (Zeidler & Sadler, 2007; Zeidler et al., 2005).

SSI is purported to provide students with an awareness of the role evidence has in science and the value placed on its procedural or associated methodological features such as evaluating the veracity and credibility of scientific claims (Kolstø et al., 2006; Sadler, 2009; Zeidler et al., 2002). Moreover, research in SSI has shown student improvement in informal reasoning and reflective judgment (Sadler & Zeidler, 2005; Zeidler et al., 2009), while improving their ability to recognize the rigor, legitimacy, and veracity of scientific claims sufficient to discern science from pseudoscience (Kolstø et al., 2006; Osborne et al., 2004). The relevant context which is the hallmark of SSI, gives the foundation from which reason may be exercised (Zeidler et al., 2005). It is from this practice in reasoning that gives promise for graduating students with potentially higher levels of SL and SSR abilities resulting in improved capacity to recognize the charlatans of flimflam and make better use of their scientific knowledge and research skills. Research from classrooms using SSI clearly documents student gains in reasoning, argumentation quality (Kolstø et al., 2006), science content (Applebaum et al., 2006; Sadler & Zeidler, 2004b), NOS (Khishfe & Lederman, 2006; Lewis et al., 2006), and overall conceptual understanding resulting from SSI based instruction (Venville & Dawson, 2010; Zeidler et al., 2002; Zohar & Nemet, 2002). Together, these advancements in students' recognition and critical assessment of scientific claims ought to increase their level of SL and the likelihood those skills will be utilized whenever introduced to new scientific information.

Socioscientific Issues in the Classroom

Students can gain content knowledge with or without SSI, but what makes SSI unique is how it manages multiple outcomes (e.g., SL, NOS, SSR), referred to as its "unification power" by Zeidler et al. (2005, p. 371). This "unification power" is responsible for bringing into play most of the likely variables that interact amid these quasi-authentic scenarios in a particular context that require reasoning faculties few students have had practice utilizing (Zeidler et al., 2005). By promoting high student engagement through relevant social problems rooted in scientific disciplines, SSI has been shown to minimize classroom management issues while providing problem solving and content acquisition opportunities (Sampson, Grooms, & Walker, 2011). In addition, SSI attends to the moral development of young learners through the exploration of social and personal issues that invoke such perspectives, thereby, creating a learning environment more meaningful and personal (Zeidler & Keefer, 2003). When considerations are then given to moral issues in determining decisions or actions, students naturally become vested in the problem at a level rarely practiced in school.

Although numerous studies of SSI in the classroom have documented gains in student's conceptual understanding and informal reasoning while outperforming other students in areas of content (Applebaum et al., 2006; Kolstø et al., 2006; Sadler et al., 2007; Zohar & Nemet, 2002), Duschl (2007) discovered tensions among many teachers implementing it in their classrooms. Mirroring this sentiment, Lewis and Leach (2006) found lack of time, uncertainity in selecting relevant topics, and classroom managemnent issues among some of the most prevailing reason undermining implementation. Furthermore, Aikenhead (2006) explains the situation as paradoxal given "the greater the social or cultural relevance associated with canonical content, the greater the student motivation, but the greater the complexity to learn it meaningfully" (p. 85) Implementing SSI into the curriculum, not as an add-on, but to integrate it throughout the length of the course provides students with a predictable structure that becomes manageable over time. Where opportunities do exist for such immersion in contextual learning, students will become more participatory while classroom management issues subside as students become familiar with the structure (Zeidler, Applebaum, & Sadler, 2011).

Argumentation

Equally important as the epistemology of scientific knowledge with respect to NOS is the ability to practice the process of argumentation. Argumentation is considered to be integral to the manner by which science is produced (Osborne, 2010) and is a necessary component of SSI. Through the very nature of the process, argumentation is essential to understanding NOS and can enhance conceptual understanding as well as scientific reasoning. Given argumentation's key role as a central activity in scientific communities, learning about science would be grossly deficient without opportunities involving discursive practices that allow students to apply their understandings of science to personal decisions with socio-cultural and environmental implications (Driver et al., 2000; Kuhn, 2010; Muller & Zeidler, 2010). Sadler (2006) describes discursive practice as a part of argumentation that includes: evaluating evidence; assessing alternatives; establishing the validity of scientific claims; and addressing counterevidence. If the products of science are knowledge claims, then it is through argumentation and critical analysis of evidence that this particular means of knowing and its conclusions become trustworthy (Osborne et al., 2004).

Driver et al. (2000) describes argumentation as a rational process relying on the rigorous application of knowledge evaluation criteria to reach some consensus or acceptable agreement on claims or actions. More importantly, Osborne (2010, p.463) reminds us that “knowing what is wrong matters as much as knowing what is right”. Developing criteria for evaluating knowledge claims and determining what counts as reliable data from these discursive activities satisfies another tenet of SL – the ability for students as future students and citizens to recognize pseudoscience and establish credibility in scientific claims (Deboer, 2000). Again, this ability makes it possible for students to eschew unscientific claims and propaganda associated with socially controversial theories for more rational and credible conclusions from science. This section establishes the merit of argumentation in the classroom and how SSI is the appropriate framework in accommodating those dialogical practices.

Researchers have long documented the benefits of scientific argumentation in classrooms and continue to acknowledge the importance of discursive practices in the acquisition of scientific knowledge (e.g., Driver et al., 2000; Erduran, Simon, & Osborne, 2004; Kuhn, 1993; 2010; Sadler, 2006; Zeidler et al., 2003). In addition, research from argumentation in the science classroom supports its use as an effective tool or framework within SSI for purposes of learning SL and NOS while practicing SSR (Jimenez-Aleixandre & Erduran, 2007; Zeidler & Sadler, 2011). Argumentation is involved with science more in the process than the outcomes, in ways that it is situated in science through communication, higher order learning and thinking processes, components of NOS, and more specifically, considerations of SSI (Jimenez-Aleixandre & Erduran, 2007). With respect to the epistemology of science, argumentation assists in the enculturation of students into the practices of the scientific culture and the importance of epistemic criteria for knowledge evaluation when confronted with divergent viewpoints or in considering alternatives (Jimenez-Aleixandre & Erduran, 2007). Specific to the claims of this paper, argumentation facilitates the achievement of SL and empowerment of students as future citizens while developing skills of SSR (Jimenez-Aleixandre & Erduran, 2007; Sadler et al., 2007; Zeidler & Sadler, 2011).

Underlying many investigations into argumentation is a relationship between the process of argumentation and that of student understanding. Venville and Dawson (2010, p. 953) add "that student involvement in relevant, real-world argumentation is likely to contribute to understanding". Likewise, Sadler (2004) concluded from literature reviews and a later study (Sadler & Fowler, 2006) that increased knowledge or content understanding leads to more complex use of justifications when making arguments. Lewis and Leach (2006) showed improved argumentation after students were exposed to only a brief intervention promoting content knowledge. Greater content understanding was also positively correlated by Sadler and Zeidler (2004a) with better quality informal reasoning of high school students when negotiating genetic therapy issues. Zohar and

Nemet (2002) have also shown within one semester of promoting argumentation skills that ninth graders were able to outperform the control group on conceptual understandings, lending further support to the contention that practice in argumentation can improve content understanding. Zohar and Nemet's (2002) study found students not only constructed higher quality arguments in their post intervention analyses but were also more inclined to transfer those skills and understandings to other problems newly introduced. Important to the central claim of this paper, this sort of transfer may manifest in students' abilities to better understand and scrutinize socially controversial theories.

Argumentation is intrinsic to meaningful SSI and has been demonstrated to engage students with the promise of achieving improvements in SL, content and NOS understanding, and SSR (Sadler, 2004; 2011b; Sadler et al., 2007; Zeidler & Sadler, 2011). According to Zeidler and Sadler (2007), discourse in this fashion that derives from collaborative efforts in the evaluation of evidence and the quality of that selected serves to be the "conduit through which course content is made real and important to their lives" (p.205). Duschl (2007, p.159) finds it important for students to see "scientific inquiry as epistemological and social processes in which knowledge claims can be shaped, modified, restructured, and at times, abandoned". Thus, within a socio-cultural context, "argumentation assumes a fundamental position in the collective process of making meaning and affecting learning" (Sadler, 2006, p. 325).

Socioscientific Reasoning

SSR is a desired outcome of SSI that brings into focus all the skills and higher-order thinking practices that are able to be refined while negotiating SSI (Zeidler & Sadler, 2011). Convinced SSI is linked to a more functional SL, Sadler et al. (2007)

argue SSI education can hone those skills and aptitudes responsible for improved SL into advanced SSR skills. Preparing students to become more informed and responsible citizens with practiced SSR, regardless of their post-secondary aspirations, is more likely to be realized within the framework of SSI as opposed to more traditional lecture-based approaches. Ultimately, SSR cultivates certain reasoning skills and aptitudes in such a way that allows students to develop a deeper understanding of scientific affairs and content.

The decision-making process generally involves evaluation of information and reasoning (Kolstø, 2001). Synthesizing information from multiple disciplines while identifying various strengths and weaknesses in deciding whether or not to accept their veracity are not only considered important thinking skills but essential in citizenship education (Aikenhead, 2006). The processing skills described by Zeidler et al. (2009), such as reflective judgment, can be considered as the trait of analysis and evaluation of data and claims as opposed to uncritical acceptance on authority. This criterion of judgment cultivated and critical thinking applied to SSI, considered evidence-based reasoning has been expanded by Sadler et al. (2007) and more recently, by Zeidler and Sadler (2011) to include other reasoning skills that demonstrate the construct of SSR. SSR encompasses a particular mode of reasoning associated with SL such as flexible reasoning, questioning authority, and formulating decisions in a reflective manner when it necessarily develops from engagement in SSI. Students who develop such skills in reasoning may therefore be more inclined to consider the evidence and rationale associated with socially controversial theories with more of an open mind and less threatened manner.

While “advancing socioscientific reasoning as an educationally meaningful and assessable construct”, Sadler et al. (2007, p. 371) expects student outcomes to include: evoking skepticism; favoring on-going inquiry; examining issues from multiple perspectives; and having some understanding of the complexity inherent in the SSI. Sadler et al. (2007) introduces the construct of SSR as a tool for both practitioners and researchers to assess student practices and outcomes from SSI. Laius and Rannikmae (2011) found gains in SSR and scientific creativity among ninth graders after a literacy-based intervention from science and technology that focused on scaffolding argumentation. They found as the teacher’s knowledge and familiarity of argumentation was advanced through a longitudinal professional development program, improvements in students’ SSR skills were liable to follow. This will allow students to more fully engage in democratic duties, equip them to make more complex decisions and draw sophisticated conclusions with sound and rational reasoning, all made possible by practicing SSR in a SSI context (Sadler et al., 2007; Venville & Dawson, 2010). Outfitted with such abilities, it is argued that students will be able to examine scientific claims with greater confidence and clarity resulting in improved understanding of socially controversial theories.

Socially Controversial Scientific Theories

This final section takes a closer look at the underlying forces that affect socially controversial theories and what causes them to be one of the most challenging topics to teach (Evans, 2001). Socially controversial theories according to Hildebrand, Bilica, and Capps (2006, p. 1033) are actually considered "science education controversies" since the teaching of such topics cannot be easily resolved with additional science instruction or appeal to evidence. Rather, the controversy arises from outside the discipline and carries with it a wide range of considerations not necessarily related to science, including social, political, and religious issues. However, the use of the term 'socially controversial' will remain the label of choice here since a clear demarcation of its meaning is readily obvious.

Regarding the general purpose of teaching such topics, questions arise as to whether the goals are specific content understanding or more absolute acceptance of the theories presented. The answer is straight forward. According to the standards, the aim is to facilitate student's conceptual understanding, not acceptance (e.g., AAAS, 1993; FDOE, 2008; NRC, 2011). Most teachers, save those involved in research, may never ascertain student's views on acceptance and would not regard acceptance as one of their teaching objectives. This paper promotes SSI education for developing students' abilities to critically examine and scrutinize scientific claims with the anticipation that these reasoning skills will develop a deeper understanding of socially controversial topics.

Although many would agree as self-evident that understanding leads to acceptance (Rutledge & Mitchell, 2002), it is not identified in the literature as a pursuable goal for science education. The discussions regarding acceptance as a measureable point of reference, not necessarily a direct consequence of understanding, have been a reflection of the research reviewed rather than a prescribed goal in the standards of science education. The notable implication for science education is to focus on imparting the skills and practice for students to acquire advanced understanding of scientific knowledge in a SSI context, and therefore, become better equipped to make informed and rational decisions in pursuit of advanced understanding, regardless of whether or not they accept socially controversial theories.

Students and Understanding

The results of learning scientific theories are ultimately determined by the students who bring to the classroom a myriad of factors and characteristics that influence their understanding and levels of acceptance (Evans, 2001). Examining the factors influencing the acceptance of evolution among pre-service biology teachers, Ha, Haury, and Nehm (2012) perceptively proposed a model of the inter-relationships responsible for acceptance that includes attention to "non-conscious intuitive cognitions that give rise to feeling of knowing" (p. 95). Their model uniquely represents the interplay between conscious and intuitive cognitions when one is determining what to believe. Measuring these products of intuitive cognition, Ha et al. (2012) discovered the feeling of knowing has significant influence on the student's level of acceptance. Other studies identified religious identity as the major influential factor that not only negatively affected acceptance but also course achievement (Berkman & Plutzer, 2010). For example, among college students holding Creationist views while attending biology and zoology courses, Lovely and Kondrick (2008) noticed a significant decrease in student achievement linked with students' preconceived notions regarding creationism. In a similar study decades earlier, Lawson and Worsnop (1992) found high school students' beliefs in creationism were very resistance to change and negatively correlated with advancements in reflective reasoning skills as well as course achievement.

Brem, Ranney, and Schindel (2003) also observed college freshman who maintained ideas with negative connotations in respect to the acceptance of evolution. It would appear that associated with the acceptance of evolution are negative consequences such as the alleged justification of racism or selfish behavior while having to abandon a sense of purpose, higher power, and moral standards (Brem et al., 2003). Sacrificing a belief in creationism for acceptance of a naturalistic explanation leaves many students in a most undesirable position of having to separate from their parents and religion – and many won't (Berkman & Plutzer, 2010). Students whose religious worldview calls for absolute certainty and truth, according to Donnelly, Kazempour, and Amirshokoohi (2007), may not accept the elements relating to NOS, such as its tentativeness or empirical nature. Furthermore, this supposed tolerance for a non-evidential way of knowing, may leave students unable to scrutinize scientific theories.

In a more positive direction, sophisticated views of NOS were found by Sinatra, Southerland, McConaughy, and Demastes (2003) to be indicative of students possessing more positive beliefs and attitudes toward socially controversial theories, specifically evolution. When explicitly teaching NOS alongside such theories, other investigators have also found students viewing the topic as nonthreatening and typically became more accepting because the increased understanding they had of the process by which these theories were established (Cavallo & McCall, 2008; Clores & Limjap, 2006). Positive attitudes about science and adequate understandings of NOS should facilitate one's understanding and eventual acceptance of scientific theories since there is less resistance and difficulty in accepting the supporting evidence as trustworthy and credible (Clores & Limjap, 2006; Ingram & Nelson, 2006). Ingram and Nelson (2006) submit that pedagogical techniques that address students' attitudes such as those inherent in SSI education can directly impact student's attitudes and subsequent achievement in more positive and motivational ways.

Undeniably, there is a fine line teachers must walk when issues of religion are concerned and many are reluctant to address them in class (Nelson, 2008). In fact, Rutledge and Mitchell (2002) discovered as many as 43 percent of biology teachers in Indiana avoid teaching evolution simply because of its controversial nature. However, specific religious convictions are unreasonable by scientific standards and need to be addressed in the context of NOS in order to distinguish them from other ways of knowing (Cracraft, 2004; Long, 2012). Just as it is expected students know the difference between astronomy and astrology, or chemistry and alchemy by how that knowledge came to be, evolution should also be differentiated from creationism (Lovely & Kondrick, 2008). With respect to teachers and their understanding of NOS when teaching evolution, Rutledge and Mitchell (2002) concluded that the more understanding of NOS and level of acceptance for evolution determined a greater teaching preference. In contrast, Nehm and Schonfeld (2007) caution that despite gains in teachers' understanding of NOS and evolution as a result of college level coursework, they found no correlation with increased preference for its teaching or any change in the position of those teachers who did not accept evolution prior to the course.

Other investigators have correlated biology teachers' strong religious conviction and academic background to poor understanding of evolution theory and NOS concepts, which ultimately, determined their low teaching preference (Nelson, 2008; Trani, 2004). The concern, explains Long (2012), is the fact that pre-service teachers are among the most religious college majors and can potentially amount to a direct impediment to the teaching of evolution in the classroom. His suggestion of mandating a college course on evolution for pre-service teachers is not only with the intention of increasing understanding but to pose as an effective deterrent for Creationists considering majoring in education. Meanwhile, a less radical approach is to have SSI-based instruction frequent enough that it may be able to minimize these ill-effects stemming from negative attitudes either preconceived or elicited during instruction. Because of its promise of heightened student engagement and ownership of the learning (Rutledge & Mitchell, 2002) as well as the social nature of SSI activities (Sadler & Klosterman, 2009), SSI is the best pedagogy for such ends. Therefore, by learning NOS as well as other skills; students are better equipped to critically examine theories independent of the prejudices of the teacher. Students, therefore ought to achieve sufficient conceptual understanding, albeit distal from the immediate goals of science education, that eventually progresses toward higher levels of acceptance.

The level of that acceptance, at least among science majors in college, has been positively correlated by Gregory and Ellis (2009) with the level of conceptual understanding a student possesses. Those accepting evolution were also found to hold more sophisticated conceptualizations of NOS. Conversely, Sinatra et al. (2003) discovered no relationship between college students' level of understanding regarding evolution and its acceptance. A Creationist may understand the theory quite well but not come to accept it, and likewise, one who lacks significant understanding may pledge his or her acceptance by simply deferring to authority. Interestingly, Lovely and Kondrick (2008) witnessed a 50 percent split of students who were undecided at the beginning of a biology course shift toward Creationist views, concluding that more education of the evidence and mechanics of evolution did not necessarily determine those final alliances. The degree of willingness to examine one's beliefs and remain open minded to alternative points of view were found by Sinatra et al. (2003) to be key points in developing students' understanding. Thus, final acceptance of evolution may be linked to more social and philosophical issues well beyond the control of science education.

Students' religious convictions and belief-based preconceptions can undermine even the best strategies and techniques used to teach such topics when they are perceived to be in conflict with the material presented (Berkman & Plutzer, 2010; Long, 2012). Lovely and Kondrick (2008) discovered these a priori beliefs can further handicap the student in metacognitive ways that effectively prevent deeper understanding because they tend to supersede or otherwise, obfuscate evidence presented and impede logical conclusions from being rationally considered. Although the study observed in-service and pre-service teachers, investigators have found similar issues of religiosity not only suppressing the teaching of evolution, but may prevent individual teachers from any meaningful understanding of the theory (Berkman & Plutzer, 2010; Griffith & Brem, 2004). Woods and Scharmann's (2003) survey supports the strong influence religion has on acceptance, finding only less than 20 percent of students feel their religion does not interfere with their acceptance of evolution. While the majority of Americans consider evolution to be scientifically valid and worth teaching, only half actually accept it. In fact, the other half of our population still believes the earth to be only 10,000 years old (Scott, 2005). It may appear that unintelligent and scientifically illiterate individuals comprise the majority of evolution skeptics, however, Miller (2004) showed only a small correlation of advanced levels of SL to the acceptance of evolution. Suggesting that SL may not be the major influence determining acceptance, whereas post-secondary education proved more indicative of acceptance, as it was four times more likely for someone holding an advanced degree to accept evolution. Using more recent survey data, Berkman and Plutzer (2010) concluded that not only must individuals be intelligent to make informed opinions on evolution, but high cognitive abilities also leads to greater support and acceptance of evolution.

Concluding Remarks

Although evolution dominated these discussions of socially controversial theories, other, less controversial theories, such as climate change and the Big Bang, are thought to be approached by students in a similar fashion. It has become clear that core beliefs, religious convictions, and other dispositions of both teachers and students may remain problematic to the teaching and understanding of theories riddled with political, cultural and social controversy. Efforts towards implementing SSI, however, should not wane in spite this admission. Rather, confidence in the SSI framework to best appropriate skills and knowledge to students remains impregnable and at the present, represents the most flexible and accommodating teaching practice that can handle so many issues and concerns from so many sources, both in and out of the classroom (Zeidler et al., 2005). Given an ever increasing frequency and scope of potential SSI in current media, from local disputes to global crises, SSI should assume a more prominent role in science education. Relevant literature has been reviewed to build the case for SSI inclusion in the curriculum where it can serve as the context for teaching and learning that promotes SL on a global scale as well as provide the conduit for citizenship and character education reform to flow. Providing practice for students to negotiate SSI (i.e., to weigh evidence, interpret text, and evaluate the veracity of claims), ought to result in empowering them to not only make more informed and balanced decisions about relevant SSI in their everyday lives, but extend this to considering any matters of science.

SSI imparts skills and abilities, albeit ones inherently more difficult to assess (e.g., SL, NOS, critical thinking), of a more pragmatic and applicable nature, qualities that go well beyond the classroom. Once students have had the opportunity to engage in discursive activities in a SSI context, the development and cultivation of skills to craft more sophisticated arguments as well as improve SL, NOS understanding, and SSR is expected to follow. In turn, these skills and understanding encourage students to critically examine scientific evidence, regardless of the theory, from a more advanced SL perspective grounded in NOS with more sophisticated SSR abilities. Furthermore, when students gain this advanced perspective, future negotiations of scientific claims in more scientific terms becomes possible, and invariably positions students to make positive gains along a path toward a better understanding of theories presumed controversial.

References Cited

Aikenhead, G.S. (2006). *Science education for everyday life: Evidence-based practice*. New York: Teachers College Press.

American Association for the Advancement of Science (1989). *Science for all Americans:* A Project 2061 report on literacy goals in science, mathematics, and technology. Washington, DC: AAAS.

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

Applebaum, S., Barker, B., & Pinzino, D. (2006, April). Socioscientific issues as context for conceptual understanding of content. Paper presented at the National Association for Research in Science Teaching. San Francisco, CA.

Bell, R., & Lederman, N. (2003). Understandings of the nature of science and decision making on science and technology based issues. *Science Education, 87*, 352-377.

Berkman, M. B., & Pultzer, E. (2010). Evolution, creationism, and the battle to control America's classrooms. New York: Cambridge University Press.

Brem, S., Ranney, M., & Schindel, J. (2003). Perceived consequences of evolution: College students perceive negative personal and social impact in evolutionary theory. *Science Education, 87,* 181–206.

Clores, M. A., & Limjap, A. A. (2006). Diversity of students' beliefs about biological evolution. *Asia Pacific Journal of Education, 26*(1), 65-77.

Cracraft, J. (2004). The new creationism and its threat to science literacy and education. *BioScience, 54*(1), 3.

Dawson, V., & Venville, G. (2009). High-school students' informal reasoning and argumentation about biotechnology: An indicator of scientific literacy. *International Journal of Science Education, 31*(11), 1421-1445.

Deboer, G.E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science reform. *Journal of Research in Science Teaching, 37,* 582-601.

Donnelly, L., Kazempour, M., & Amirshokoohi, A. (2007, April). *Student Perceptions of evolution instruction: Understanding, acceptance, and learning experiences.* Paper presented at the annual conference of National Association of Research in Science Teaching, New Orleans, LA.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287-312.

Duschl, R.A. (2007). Quality argumentation and epistemic criteria. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 159-175). The Netherlands: Springer Press.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88*, 915-933.

Evans, E. M. (2001). Cognitive and contextual factors in the emergence of diverse beliefs systems: Creation versus evolution. *Cognitive Psychology, 42*(3), 217-266.

Gregory, T. R., & Ellis, C. A. (2008). Conceptions of evolution among science graduate students. *BioScience, 59*(9), 792-799.

Griffith, J.A., & Brem, S.K. (2004). Teaching evolutionary biology: pressures, stress, and coping. *Journal of Research in Science Teaching, 41*, 791-809.

Ha, M., Haury, D. L., & Nehm, R. H. (2012). Feeling of certainty: Uncovering a missing link between knowledge and acceptance of evolution. *Journal of Research in Science Teaching, 49*(1), 95-121.

Hildebrand, D., Bilica, K., & Capps, J. (2008). Addressing controversies in science education: A pragmatic approach to evolution education. *Science and Education, 17,* 1033-1052.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education, 25*(6), 645-670.

Ingram, E.L., & Nelson, C.E. (2006). Relationship between achievement and students' acceptance of evolution or creationism in an upper-level evolution course. *Journal of Research in Science Teaching, 43*(1), 7-24.

Jimenez-Aleixandre, M.P., & Erduran, S. (2007). Argumentation in science education: An overview. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 3-25). The Netherlands: Springer Press.

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.

Kolstø, S.D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85*, 291-310.

Kolstø, S., Bungum, B., Arnesen, E., Isnes, A., Kristensen, T., Mathiassen, K., Mestad, I., Quale, A., Tonning, A., & Ulvik, M. (2006). Science students' critical examination of scientific information related to socioscientific issues. *Science Education, 90*, 632-655.

Kuhn, D. (2010). Teaching and learning science as argument. *Science Education, 94 (*5), 810-824.

Kuhn, D. (1993). Science as argumentation: Implications for teaching and learning scientific thinking. *Science Education, 77*, 319-337.

Laius, A., & Rannikmae, M. (2011). Impact on student change in scientific creativity and socio-scientific reasoning skills from teacher collaboration and gains from professional in-service. *Journal of Baltic Science Education, 10*(2), 127-137.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education, 84*, 71-94.

Lawson, A. E., & Worsnop, W. A. (1992). Learning about evolution and rejecting a belief in special creation: Effects of reflective reasoning skill, prior knowledge, prior belief and religious commitment. *Journal of Research in Science Teaching, 29*(2), 143-166.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 831-879). Mahwah, NJ: Lawrence Erlbaum Associates.

Levinson, R. (2006). Towards a theoretical framework for teaching controversial socio-scientific issues. *International Journal of Science Education, 28*(10), 1201-1224.

Lewis, A., Amiri, L., & Sadler, T. (2006, April). Nature of science in the context of socioscientific issues. Paper presented at the National Association of Research in Science Teaching. San Francisco, CA.

Lewis, J., & Leach, J. (2006). Discussion of socio-scientific issues: The role of science knowledge. *International Journal of Science Education, 28*(11), 1267-1287.

Liu, S-Y., Lin, C-S., & Tsai, C-C. (2011). College students' scientific epistemological views and thinking patterns in socio-scientific decision making. *Science Education 95*, 497-517.

Long, D. E. (2012). The politics of teaching evolution science education standards and being a Creationist. *Journal of Research Science Teaching, 49*(1), 122-139.

Lovely, E.C., & Kondrick, L.C. (2008). Teaching evolution: Challenging religious preconceptions. *Evolution Education and Outreach, 48*(2), 164-174.

Miller, J. D. (2004). Public understanding of, and attitudes toward scientific research: What we know and what we need to know. *Public Understanding of Science, 13*(3), 203-223.

Mooney, C., & Kirshenbaum, S. (2009). *Unscientific America: How scientific illiteracy threatens our future*. New York, NY: Basic Books.

Muller, M.P., & Zeidler, D.L. (2010). Moral-ethical character and science education: Ecojustice ethics through socioscientific issues (SSI). In D. Tippins, M. Mueller, M. van Eijck, & J. Adams (Eds.), *Cultural studies and environmentalism: The confluence of ecojustice, place-based (science) education, and indigenous knowledge systems* (pp.105-128). New York: Springer.

National Research Council (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards.* Washington, DC: National Academy Press.

National Research Council (1996). National science education standards. Washington, DC: National Academy Press.

Nehm, R.H., & Schonfeld, I.S. (2007). Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools? *Journal of Science Teacher Education, 18*, 699-723.

Nelson, C.E. (2008). Teaching evolution (and all of biology) more effectively: Strategies for engagement, critical reasoning, and confronting misconceptions. *Evolution Education and Outreach, 48(*2), 213-225.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328* (5977), 463-466.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10): 994–1020.

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 729-780). Mahwa, New Jersey: Lawrence Erlbaum Associates.

Roth, W.M., & Barton, A.C. (2004). *Rethinking science literacy*. New York: Routledge Falmer.

Rutledge, M.L., & Mitchell, M.A. (2002). Knowledge structure, acceptance & teaching of evolution. *The American Biology Teacher, 64*(1), 21-28.

Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Science Education, 36*, 1-44.

Sadler, T.D. (2011a). Situating socio-scientific issues in classrooms as a means of achieving goals of science education. In T.D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning, and research* (pp.1-10). The Netherlands: Springer Press.

Sadler, T.D. (2011b). Socio-scientific issues-based education: What we know about science education in the context of SSI. In T.D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning, and research* (pp.355-369). The Netherlands: Springer Press.

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

Sadler, T. D. (2006). Promoting discourse and argumentation in science teacher education. *Journal of Science Teacher Education, 17*, 323-346.

Sadler, T. D. (2005). Evolutionary theory as a guide to socioscientific decision-making. *Journal of Biological Education 39*(2), 68-72.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*(5), 513-536.

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education, 37*, 371-391.

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualisations of the nature of science in response to a socioscientific issue. *International Journal of Science Education, 26*(4), 387-409.

Sadler, T. D., & Fowler, S.R. (2006). A threshold model of content knowledge transfer for socioscientific argumentation. *Science Education 90*, 986-1004.

Sadler, T. D., & Klosterman, M. L. (2008). Exploring the sociopolitical dimensions of global warming. *Science Activities 45*(4), 9-12.

Sadler, T. D., Klosterman, M. L., & Tpocu, M. S. (2011). Learning science content and socio-scientific reasoning through classroom explorations of global climate change. In T.D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning, and research* (pp.45-77). The Netherlands: Springer Press.

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching 46*(8), 909-921.

Sadler, T.D., & Zeidler, D.L. (2005). Patterns in informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching 42*(1), 112-138.

Sadler, T.D., & Zeidler, D.L. (2004a). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education, 89*, 71-93.

Sadler, T.D., & Zeidler, D.L. (2004b). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education, 26*(4), 387-409.

Sampson, V., Grooms, J., & Walker, J. (2011). Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. *Science Education, 95*, 217-257.

Scott, E.C. (2005). *Evolution vs. creation: An introduction*. Berkeley, CA: University of California Press.

Shamos, M. H. (1995). *The myth of scientific literacy*. New Brunswick, N.J.: Rutgers University Press.

Sinatra, G., Southerland, S., McConaughy, F., & Demastes, J. (2003). Intentions and beliefs in students' understanding and acceptance of biological evolution. *Journal of Research in Science Teaching, 40*, 510–528.

Trani, R. (2004). I won't teach evolution: It's against my religion. And now for the rest of the story. *The American Biology Teacher*, *66*(6), 419-427.

Venville, G. J., & Dawson, V. M. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. *Journal of Research in Science Teaching*, *47*(8), 952–977.

Woods, C. S., & Scharmann, L. C. (2003). High school students' perception of evolutionary theory. *Electronic Journal of Science Education*, *6*(2). Retrieved August 10, 2011, from http://unr.edu/homepage/crowther/ejse/woodsetal.html.

Wu, Y-T., & Tsai, C-C. (2011). High school students' informal reasoning regarding a socio-scientific issue, with relation to scientific epistemological beliefs and cognitive structures. *International Journal of Science Education, 33*(3), 371-400.

Zeidler, D. L., Applebaum, S.M., & Sadler, T.D. (2011). Enacting a socioscientific issues classroom: Transformative transformations. In T.D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning, and research* (pp.277-305). The Netherlands: Springer Press.

Zeidler, D.L., Osborne, J., Erduran, S., Simon, S., & Monk, M. (2003). The role of argument during discourse about socioscientific issues. In D.L. Zeidler (Ed.), *The role of moral reasoning and discourse on socioscientific issues in science education* (pp. 97–116). Dordrecht, Netherlands: Kluwer Academic press.

Zeidler, D.L., & Keffer, M. (2003). The role of moral reasoning and the status of socioscientific issues in science education: Philosophical, psychological and pedagogical considerations. In D.L. Zeidler (Ed.), *The role of moral reasoning and discourse on socioscientific issues in science education* (pp. 7-33). Dordrecht, Netherlands: Kluwer Academic press.

Zeidler, D.L., & Sadler, T.D. (2011). An inclusive view of scientific literacy: Core issues and future directions. In Linder, C., Ostam, L., & Wickman, P. (Eds.), *Promoting scientific literacy: Science education research in transaction* (pp. 176-192). New York: Routledge / Taylor & Francis Group.

Zeidler, D.L., & Sadler, T.D. (2008). Social and ethical issues in science education: A prelude to action. *Science and Education*, *17*, 799-803.

Zeidler, D.L., & Sadler, T.D. (2007). The role of moral reasoning in argumentation: Conscience, character and care. In S. Erduran & M. Pilar Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 201-213). The Netherlands: Springer Press.

Zeidler, D.L., Sadler, T.D., Applebaum, S., & Callahan, B.E. (2009). Advancing reflective judgment through socioscientific issues. *Journal of Research in Science Teaching*, *46*(1), 74-101.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research based framework for socioscientific issues education. *Science Education, 89*(3), 357–377.

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

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*, 35–62.