SEE-SEP: From a separate to a holistic view of socioscientific issues

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Abstract

The trend of socioscientific issues (SSIs) has been emergent in the science- and technology-dominated society of today. Accordingly, during the past 20 years, students' skills of argumentation and informal reasoning about SSIs have achieved greater emphasis and profile in school education. Based upon the importance of SSIs, more and more researchers have investigated how students reason and make arguments about SSIs, and also explored the dimensions influencing students' arguments and also involved in the various SSIs. This article has a threefold purpose. Firstly, we want to address the different roles of SSIs in science education nowadays, and secondly, after reviewing the divergent dimensions involved in SSIs from previous literature, we want to provide a holistic view to represent the essence of SSIs via the SEE-SEP model (connecting six subject areas of Sociology/culture, Environment, Economy, Science, Ethics/morality and Policy with three aspects of value, personal experience and knowledge) developed here. Thirdly, to support the SEE-SEP model, examples extracted from former studies are presented. The implications for research and for school science education are discussed.

Introduction

The complex interrelationship between science and society has been become apparent in the modern age (Sadler & Zeidler, 2005a). More and more issues concerning the interaction of science and society emerge nowadays, and those issues have been termed socioscientific issues (SSIs) (Kolstø, 2001; Patronis, Potari, & Spiliotopoulou, 1999; Sadler & Zeidler, 2005a, 2005b; Zeidler, Walker, Ackett, & Simmons, 2002). During the past 20 years, SSIs have become one of the main trends in the field of science education, and also, many researchers have perceived the significance of SSIs and emphasized the need to design issue-based curricula as part of the canon of school science (Driver, Newton, & Osborne, 2000; Pedretti, 1999; Sadler & Zeidler, 2004). SSIs could be connected to many different disciplines like biology (e.g. cloning and genetic engineering), chemistry (e.g. DDT and Dioxin), medicine (e.g. gene therapy and vaccine issue), physics (e.g. nuclear power), and environmental science (e.g. global warming); and we could say those issues can be discussed through a lens extending from a local to global scale. Global issues relate to issues that exist without any geographical boundaries. People from different countries worldwide may face and discuss the same topics, like genetically modified food (GMF), cloning technology, global warming, the use of cellular phones, nuclear power, and so on. Furthermore, there are some local SSIs important for specific areas or countries. For instance, whether people from poor countries should keep using DDT to kill mosquitoes and to decrease the number of deaths caused by Malaria; whether we should build a new freeway for reasons of economy and convenience, although it might destroy the ecology locally. However, no matter that SSIs are global or local issues, they are all related to important aspects of our future, such as the well-being of humans and other living beings.

Based on analysis of such emergent and varied SSIs, the purpose of this article is to point out the significant roles SSIs could serve in school education, and also, present different dimensions involved in reasoning or arguing about SSIs from former studies. In the end, we feel a need to try to provide a holistic view of SSIs via the SEE-SEP model with supporting evidence from past research results. Hopefully, this article could benefit the practice of research and education as well as raise more discussion in science education.

What can SSIs do in science education?

The significance of SSIs has been perceived in recent decades, and science educators are encouraged to embed SSIs in science teaching. However, what outcomes could be achieved through SSIs instruction becomes important for teachers. In this section, the main roles of SSIs in science education are presented through a literature review. We hope the clarification of these roles could help teachers to foresee the outcomes while considering adopting SSIs in their science teaching.

Role 1: Beyond STS to the achievement of scientific literacy

Following the rise of global SSIs, like energy issue and global warming, it is not hard to notice the significance of addressing the strengths and limits of science and technology in school education and in society. In line with this, Science-Technology-Society (STS) is an important notion which has been conveyed for more than 50 years (Chang, Yeung, & Cheng, 2009; Sadler, 2004b).

STS certainly is the most widespread and long-lived movement to date for stressing the inter-complexity of science, technology and society. In the Forty-sixth Yearbook regarding Science Education in American Schools, the National Society for the Study of Education/NSSE (1947) has pointed out that science instruction in general education should have broad integrative elements and students need to know the relationship of science with problems of human society. The Yearbook Committee also expressed the notion that scientific developments also had the potential to cause harm to society, and the public needs to have the knowledge and skills to make rational judgments about those risks associated with science (DeBoer, 2000). However, the concept of STS was largely unnoticed until the 1970s. Scientific literacy was more strongly identified with science in its social context throughout the 1970s and early 1980s (DeBoer, 2000). Gallagher (1971) even mentioned that, for future citizens in a democracy, understanding the interrelations of science, technology, and society may be as important as understanding the concepts and processes of science. Then in 1982, the NSTA (National Science Teachers Association) board of directors adopted a statement entitled "Science-Technology-Society: Science Education for the 1980s." (DeBoer, 2000) More recently, the last big promotion of STS is in Project 2061, which argues that individuals ought to know that science, mathematics, and technology are human enterprises, and people need to understand the implications of their strengths and limitations (AAAS, 1989).

Along with the above-mentioned development of STS, STS teaching has been documented as a powerful approach to understanding content knowledge, promoting learning interests, and appreciating science, technology and society (Aikenhead, 1994; Aikenhead & Ryan, 1992; Yager & Tamir, 1993). However, although a lot of merits have been proposed for conducting an STS approach, some researchers have argued that STS has limitations, such as the lack of a theoretical framework (Sadler, 2004b; Shamos, 1995; Zeidler, Sadler, Simmons, & Howes, 2005). Zeidler et al., (2005) specially indicated that SSIs are conceptually related to STS education, but SSIs are connected to a more coherent sociological framework considering psychological and epistemological growth. Accordingly, the role of SSIs goes beyond STS.

Instead of the STS notion, SSIs have been indicated as suitable contexts to promote scientific literacy in the globalized world of today (Chang & Chiu, 2008; Driver et al., 2000; Hughes, 2000; Kolstø, 2001; Zeidler, Osborne, Erduran, Simon, & Monk, 2003; Zeidler et al., 2002). There is a plethora of definitions of scientific literacy (e.g. De Boer, 2000; Laugksch, 2000; Murcia, 2009). One of the most influential authors in the scientific literacy field is Jon Miller, who regards scientific literacy as a multidimensional construct. Miller (1983) defined scientific literacy as being constructed from three main aspects: (1) an understanding of the norms and methods of science (i.e. the nature of science); (2) an understanding of key scientific terms and concepts (i.e. science content knowledge); and (3) an awareness and understanding of the impact of science and technology on society. In addition, scientific literacy is focused on enhancing the life quality of individuals as well. Thomas and Durant (1987) pointed our that scientific literacy could improve the ability of an individual to cope with a science- and technology-dominated society, such as help making personal decisions concerning diet, smoking, vaccination, screening TV programs or issues regarding safety in the home and at work. No matter which definition of scientific literacy we follow, there is no doubt that SSIs could serve as a context for students to achieve scientific literacy.

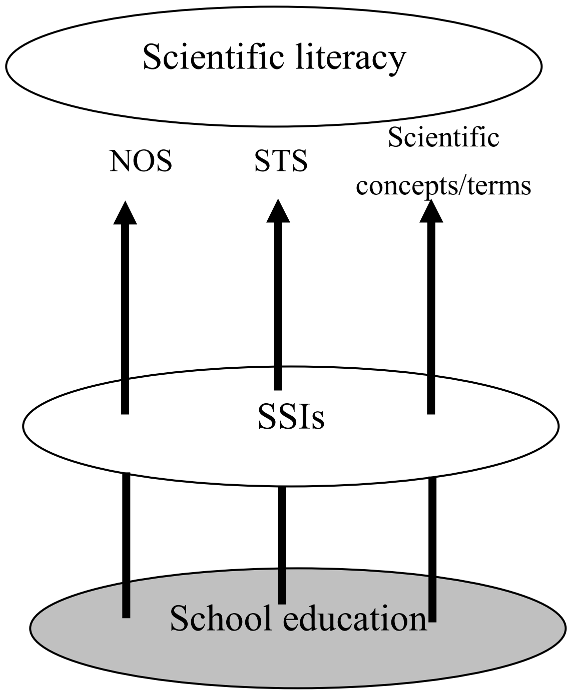
From the earlier work by Klostø (2001), he disclosed that SSI contexts could offer eight specific content-transcending topics under the four main headings of science as a social process, limitations of science, values in science, and critical attitudes, to achieve the important goal of "science for citizenship." Furthermore, in a recent paper related to SSI, Sadler and Zeidler (2009) indicated that there are invariant practices across many SSI contexts including (1) appreciating the complexity of SSI, (2) analysing issues through multiple perspectives, (3) recognizing the need for additional information and engaging necessary inquiries, and (4) possessing skepticism in reviewing information, and those invariant practices ought to be concerned in promoting scientific literacy. According to these statements, we can see that promoting SSIs is a continuous movement to accomplish the goal of scientific literacy. The way to achieve the goal of scientific literacy through SSIs is elaborated in the following sections.

Role 2: Transferring content knowledge and skills to real contexts

As mentioned before, SSIs include global and/or local issues emergent currently. In other words, SSIs are the issues debated and of concern in our daily life. To date, it seems to be a common consensus that SSIs could serve as a scenario to cultivate and evaluate students' skills of informal reasoning and informal argumentation through students' science communication (Chang & Chiu, 2008; Means & Voss, 1996; Sadler & Zeidler, 2005b; Voss, Perkins, & Segal, 1991; Zeidler et al., 2003; Zohar & Nemet, 2002); and also, whether students could transfer the content knowledge to make argumentation has also been addressed (Chang & Chiu, 2008; Ekborg, 2008; Jallinoja & Aro, 2000; Keselman, Kaufman, & Patel, 2004; Wynne, Stewart, & Passmore, 2001). Although some studies have revealed that the application of scientific concepts or content knowledge in SSI argumentation bears no relation to the quality of arguments (Kuhn, 1991; Means & Voss, 1996; Perkins, Faraday, & Bushey, 1991; Sadler & Donnelly, 2006), as science educators, we maintain the hope that students could make decisions based upon scientific concepts and evidence, or in other words, to think scientifically. Accordingly, SSIs could help students to transfer the content knowledge and skills of argumentation to a real context.

Figure 1 shows the relationship among school education, SSIs and the goal of scientific literacy. According to Millar and Osborne (1998), a scientifically literate individual could be simply defined as a person who understand the nature of science (NOS), science-technology-society (STS), and scientific concepts/terms. Through the context of SSIs, students need to know the impact of scientific and technological developments on society, which is similar to the STS idea as mentioned before (Chang et al., 2009; Sadler, 2004b; Zeidler et al., 2005). In addition, the skill of informal argumentation developed from SSIs could benefit student's ability to think scientifically or make better decisions (Chang & Chiu, 2008; Means & Voss, 1996; Sadler & Zeidler, 2005b; Voss et al., 1991; Zeidler et al., 2003; Zohar & Nemet, 2002) and to be aware of the limitations of science and technology, which corresponds to the notion of NOS (Zeidler et al., 2002). Further, via discussing or perceiving SSIs, students can also come to know scientific concepts and terms developed from science and technology (Chang & Chiu, 2008; Ekborg, 2008; Jallinoja & Aro, 2000; Keselman et al., 2004; Wynne et al., 2001). Taking the energy issue as an example, when students need to argue about whether their government should build up more nuclear plants, they need to not only have the knowledge related to energy and chemistry, but also possess the ideas regarding the impact on society and environment. Then students ought to have the skills of argumentation to provide reasons and make a claim accompanied by the considerable pros and cons of their arguments. Accordingly, we could say that SSI is a suitable context to help students transfer content knowledge and skills to their life in the modern age. The same notion has been pointed out by researchers worldwide (Driver et al., 2000; Hughes, 2000; Zeidler & Keefer, 2003; Zeidler et al., 2003; Zeidler et al., 2002).

Figure 1. *The relationship between school education, SSIs and scientific literacy.*



Role 3: Enhancing decision making and critical thinking

Aiming at democratization, science educators have also indicated the need and relevance of, and emphasized the importance of, decision-making in science teaching. The ability to make informed decisions on science- and technology-related social issues has been considered an important aspect of achieving scientific literacy worldwide (Aikenhead, 1985; Chang & Chiu, 2008; Eggert & Bögeholz, 2009; Lee, 2007; Millar & Osborne, 1998; MOE, 1998; Sadler, 2004a; Zeidler et al., 2005). It has been revealed that personal value or belief is very often involve in an individual's argumentation about SSIs. However, the SSI context could help students, in a systematic way (i.e. argumentation instruction), to engage in argumentation or decision-making. For instance, students need to decide whether smoking should be banned in all restaurants (Lee, 2007); whether they want to consume GMO (Chang & Chiu, 2008; Ekborg, 2008); whether the government should build a new road in their school area (Patronis et al., 1999), and so on. These issues are all close to students' personal lives, and furthermore, students might have been confronted with those issues in person, which encourages them to engage more in thinking critically and then making informed decisions.

Findings also support the assertion that the ability to evaluate evidence and think critically could be cultivated well through a SSI context, such as smoking, food consumption, global warming, pollution and diversity, the use of mobile phone and so on (Albe, 2008; Kolstø et al., 2006; Lee, 2007; Maloney, 2007).

Role 4: Promoting science communication

As mentioned before, the skills of informal reasoning and informal argumentation are often connected to SSI instruction or discussion. Through instruction on argumentation, students could learn how to make a good argument while dealing with SSIs. The design of instruction could, for instance, present models of argumentation suggested in the science education literature and let students work on arguing about SSIs according to each model (Chang, 2007; Erduran, Simon, & Osborne, 2004; Osborne, Erduran, & Simon, 2004); design an inquiry-based curricular unit to promote student discourse and debate on SSIs (Walker & Zeidler, 2007); use role-play to have students perform their opinions (Albe, 2008; Simonneaux, 2001; Simonneaux & Simonneaux, 2009), and so forth. Except from instructional design, very often, the ways to evaluate students' reasoning and argumentation about SSIs have been conducted through interviewing students (Sadler & Zeidler, 2005b), students' written reports (Chang & Chiu, 2008; Kolstø et al., 2006), group discussions (Kelly, Crawford, & Green, 2001), on-line chat (Walker & Zeidler, 2007), or a combined approach (Kelly & Chen, 1999; Kelly, Druker, & Chen, 1998; Walker & Zeidler, 2007). Through these approaches, students also have the opportunity to be trained and present their ideas explicitly and systematically, thus promoting their abilities in communicating science.

Role 5: Inducing interest in learning science

More and more evidence indicate that SSI-based instruction could enhance students' learning interests. The reasons could be categorized as follows: (1) the method used in SSI instruction, like role-play and debate approaches (Albe, 2008; Simonneaux, 2001), which could engage students more in learning; (2) the multifaceted character of SSIs, which could present science in the broader contexts of society, economy and so on (Sadler, 2004a); (3) the ill-structured, controversial and undetermined features of SSIs could bring a greater participant interest, such as that students have been shown to be more interested in the moral consequences of genetic engineering (Kuhn, 1991; Sadler & Zeidler, 2004; Zohar & Nemet, 2002); (4) the authentic feature of SSIs, which make students motivated and interested in learning science when the learning context involves issues that they might confront in their everyday lives (Lee, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009). Taken together, Sadler (2009a) provided a great deal of evidence from reviewing former studies to support the idea that SSI-related interventions are interesting from the perspective of students, and hence, these interventions are motivating contexts for learning. From reviewing work, Sadler even found that students who have participated in an SSI-related course were more likely to pursue science studies at the college level (Sadler, 2009a). In addition, female students' higher interests in SSI-related issues have also been revealed, which shows that an SSI-based curriculum could be seriously considered for promoting females learning interests towards science and technology (Chang et al., 2009).

Role 6: Providing cross-disciplinary concepts

As discussed above, the multifaceted character of SSIs could contribute to promoting students' learning interests. The different perspectives from students' personal values or the related evidence were found to be involved in various degrees while students dealt with different attributes of SSIs (Chang & Chiu, 2008). When the SSI is more related to environmental or ecological issues, students could frame their arguments through different points of view with regard to social, ecological, economical subject areas etc. (Patronis et al., 1999). Furthermore, moral and ethical concerns are discovered as aspects students could think about while dealing with genetic engineering (Sadler & Zeidler, 2004), thus a substantial amount of research indicates the importance of embedding moral and ethical perspective into SSIs instruction today (Sadler, 2004b; Sadler & Zeidler, 2009; Zeidler et al., 2005; Zeidler et al., 2009). Sadler and his colleagues have proposed that examining issues from multiple perspectives is one of four important aspects emerging from practicing SSIs (Sadler, Barab, & Scott, 2007). Also, SSIs are connected to the skills of argumentation, in which students need to learn how to think alternatively (Erduran et al., 2004; Kuhn, 1991; Zeidler, 1997), or consider the pros and cons of their arguments (Chang & Chiu, 2008).

Here, the basic argument for the role of providing cross-disciplinary concepts is not only the involvement of knowledge from science (i.e. the subjects of biology, chemistry and so forth), economy, society, environment, and an ethical/moral point of view, but also the skills of argumentation. Except from the content knowledge domain, other various subject areas embedded in SSIs found by students' reasoning and argumentation are described further in the following section.

The different dimensions of SSIs

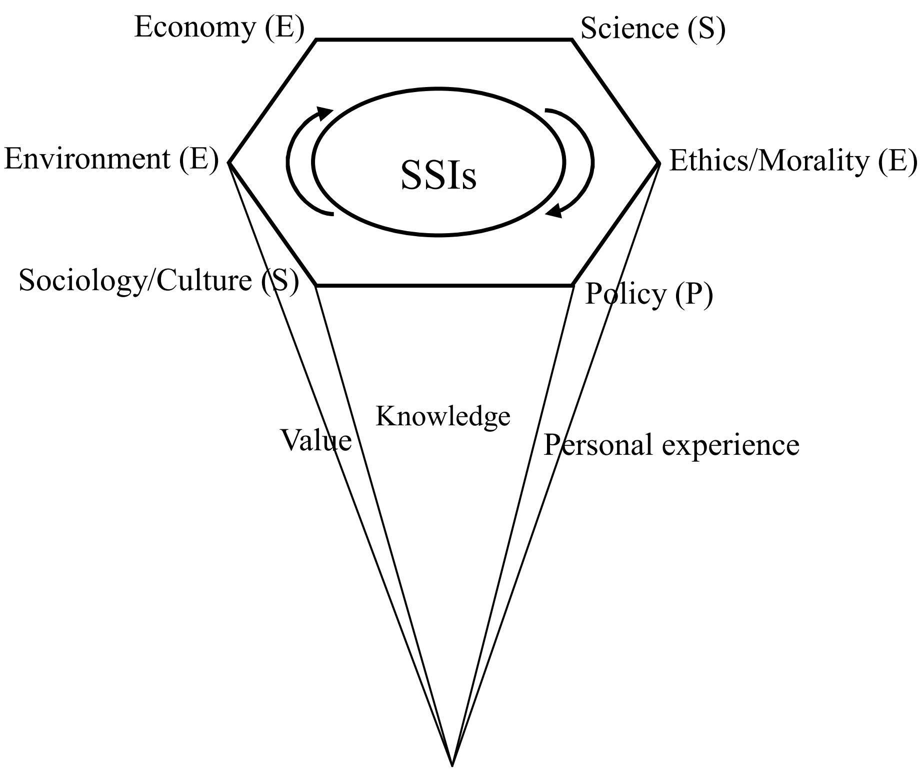
To date, more than 100 published papers highlight the emerging and cross-disciplinary topic of SSIs, and the results disclosed that many dimensions are involved in the process of students' informal reasoning and informal argumentation about SSIs, such as scientific knowledge (Albe, 2008; Chang & Chiu, 2008; Ekborg, 2008; Jallinoja & Aro, 2000; Keselman et al., 2004), or a combined perspective like individuals' personal experiences, values, ethical concerns, or governmental policy, and so on (Chang & Chiu, 2008; Fleming, 1986; Patronis et al., 1999; Sadler, 2004a; Zeidler et al., 2002). Currently, the dimensions connected to SSIs have been discussed from a broader scale, such as STS (Chang et al., 2009; Sadler, 2009b), sustainable development (Chang et al., 2009; Simonneaux, 2001; Simonneaux & Simonneaux, 2009), ethics (Sadler & Donnelly, 2006; Zeidler & Keefer, 2003; Zeidler et al., 2005), an ecological framework (Colucci-Gray, Camino, Barbiero, & Gray, 2006), or a humanistic view (Dos Santos, 2009). However, there seems to be a consensus that the important features of SSIs include complexity, multiple perspectives, inquiry and scepticism (Albe, 2008; Colucci-Gray et al., 2006; Fensham, 2008; Sadler et al., 2007; Simonneaux & Simonneaux, 2009). According to the aforesaid separate viewpoints related to SSIs, we feel the need to develop a more holistic view of SSIs, and here, we present a model entitled "SEE-SEP" to represent the essence of SSIs.

The SEE-SEP model

According to the role of SSIs in science education described above, we have discovered that cross-disciplinary concepts are involved in SSIs. Furthermore, from those empirical studies, we found that the three aspects of value, personal experiences and knowledge are influential important factors for individuals to argue about SSIs, which can be connected to different subject areas, e.g. science, sociology, environment and economy. Therefore, the main purpose of this article is to integrate the divergent concepts and develop a holistic viewpoint to represent the essence of SSIs.

Figure 2 shows the holistic model of SEE-SEP, which covers six subject areas of SSIs: sociology/culture (S), environment (E), economy (E), science (S), ethics/morality (E) and policy (P), connecting with three aspects of value, personal experiences and knowledge. SSIs are often perceived as single phenomena, hence, the aim of using the abbreviation of SEE-SEP is to make people aware of the multi-dimensional features of SSIs, and we also want people to see SSIs from the separate (SEP) subject areas. Furthermore, people could develop a more holistic view on SSIs based upon the SEE-SEP model while arguing about SSIs in daily life.

Figure 2. *The SEE-SEP model of SSI.*



Adopting an image of the benzene structure on the top aims to utilize its structure of containing a six-membered ring of carbon atoms to depict the six subject areas of SEE-SEP model together with the features of complexity and multiple perspectives. In particular, applying the circle (symbolizing the alternating single and double bonds) with two arrows in the middle of this structures intended to express the ideas that we should explore SSIs from these separate subject areas to a more comprehensive view, and also to portray the uncertainty feature (combining the aforementioned features of inquiry and scepticism) of SSIs. In addition, there is an important root grounded under the benzene structure including the three aspects of value, personal experiences and knowledge. These aspects have often been disclosed to be important factors in students' SSI reasoning or argumentation in former studies. Here, we consider that the three aspects of value, personal experiences and knowledge could be intertwined with those six subject areas, and this is the reason to locate these three aspects as a root. Accordingly, we visualize the SEE-SEP model of SSIs as a diamond structure (Figure 2). It also needs to be noticed that not all the above-mentioned subject areas and aspects can be observed in the argumentation of every SSI. In other words, the involvement of SEE-SEP is issue-dependent. More descriptions with regard to the components of SEE-SEP are delineated as follows. The supporting evidence for the SEE-SEP model will be presented in the section on the analytical framework.

The aspect of value

According to former studies related to SSI reasoning and informal argumentation, students and the public tend to make decisions about SSIs based upon their own values (i.e. cellular phone is dangerous, or is not dangerous), especially in some SSIs, in which there is no obvious evidence to prove its harmlessness or harm (e.g. Chang & Chiu, 2008). The aspect of value also includes attitudes, or we could say it is related to people's affective domain. With a very high correlation, value, attitude and affection are developed and connected strongly with an individual's socio-cultural background. Here, the socio-cultural background can be referred to not only on the larger scale of the individual's society (i.e. different religions) and culture (i.e. eastern or western), but also on the smaller scale of science community, family education, school life, and so on. When the value aspect connects to the socio-cultural subject area, we could view facts from a cross-cultural viewpoint. For example, Americans may think a cellular phone is good and important, but people living in the Amazon rain forest may think a cellular phone is useless, because the network is not built up or they do not feel the need for it in their lives. Moreover, when the value aspect meets the subject area of science, NOS and attitudes towards science are both anchored.

The aspect of personal experience

In parallel to the value aspect, it has been shown that students very often use their own personal experiences in SSI reasoning when there is no certain evidence found in relation to the SSIs. For example, regarding choosing organic food or not, some students may think about not to buy organic food, since they have tasted it before, and they felt there was no difference between organic food and others. We could say that people could argue about SSIs by using more personal experiences, when the SSIs are more connected to their daily life. Another example could be the topic of whether the government should require all restaurants to ban smoking. People who do not smoke could draw on their experiences of the unpleasant smell of smoke and vote “Yes”.

The aspect of knowledge

As science educators, we always maintain the hope that students and the public could make decisions based upon scientific knowledge and evidence. The knowledge aspect could be linked to those six subject areas through the concepts, theories, laws, or evidence developed and discovered from sociology/culture, science and technology, economy, environment/ecology, policy, or ethics/morality. Taking ethics/morality as an example, the concepts of it could relate to human welfare, justice and right, or the concepts of the welfare and rights of animals.

The subject area of sociology/culture (S)

As mentioned in the aspect of value, sociology/culture is strongly connected to value, attitude and affect, but also, regarding the knowledge aspect, people could provide the concepts or theories from sociology/culture to support their argument of SSIs. Additionally, people could provide their personal experiences from different societies or cultures to make SSI decisions. In this case, it is connected to personal experiences.

The subject area of environment (E)

More and more SSIs nowadays are related to environmental and ecological subject areas, such as the use of cars, nuclear power, global warming and also GMOs. According to the many SSIs that are connected to environment, we separate the environment subject area from the science subject area, although environmental science (including ecology) is one of the domains in biology. In so doing, we hope to be explicit about the importance of it, and also want to stress that students and the public could and should discuss or deal with SSIs with a concern about environment and ecology. This would also apply for scientists while conducting their research. An example concerning the value aspect involved into this subject area could be some kinds of local issues such as whether we should build a new freeway in the country side. Some people may think it is good for the economy (connected with the economy subject area), but some people think it is bad for the local ecology.

The subject area of economy (E)

While arguing about SSIs, the economic situation could be one of the concerns. For example, using DDT to kill mosquitoes and eliminate the Malaria problem in a poor county is acceptable to some individuals, since the poor economic status of a country influences people to think saving lives from disease is the first priority. Based upon the framework of sustainable development, economy is taken as one of the three main subject areas to consider, besides the social and the environmental subject areas.

The subject area of science (S)

For a science educator, making students apply scientific knowledge in their daily lives is one of the important goals. SSIs can serve as an authentic context for students to apply what they have learnt. Therefore, scientific knowledge from different subjects (i.e. biology, chemistry, technology, medicine, and so on) ought to be embedded into individuals' thinking processes. However, scientific concepts could be wrongly applied in the SSIs by students, which ought to be noticed more by teachers. In relation to the personal experience aspect, students may argue about SSIs based on their experiences from conducting scientific studies. Again, attitudes towards science and the notion of NOS are related to the value aspect.

The subject area of ethics/morality (E)

Ethical and moral concerns have been discussed and stressed a lot in science education while dealing with SSIs today. In addition to the viewpoint of ethics and morality, the concern of humanity could be embraced in this subject area as well. We deem that ethics/morality can often be associated with the sociology/culture subject area and the value aspect, e.g. cloning technology is acceptable or not acceptable (an issue that can be related to religious beliefs).

The subject area of policy (P)

Some people like to make SSI decisions according to the policy or law made by the government. In other words, we could say this group of people trust and rely more on their government or authority. For instance, some people may support that we should develop a new nuclear power plant, because they trust the ability of their government. We could also see that policy/law can be involved in other SSIs, such as cloning technology, abortion, global warming and so on, where people may think the government should make laws to constrain people's behaviour.

The analytical framework and evidence supporting SEE-SEP

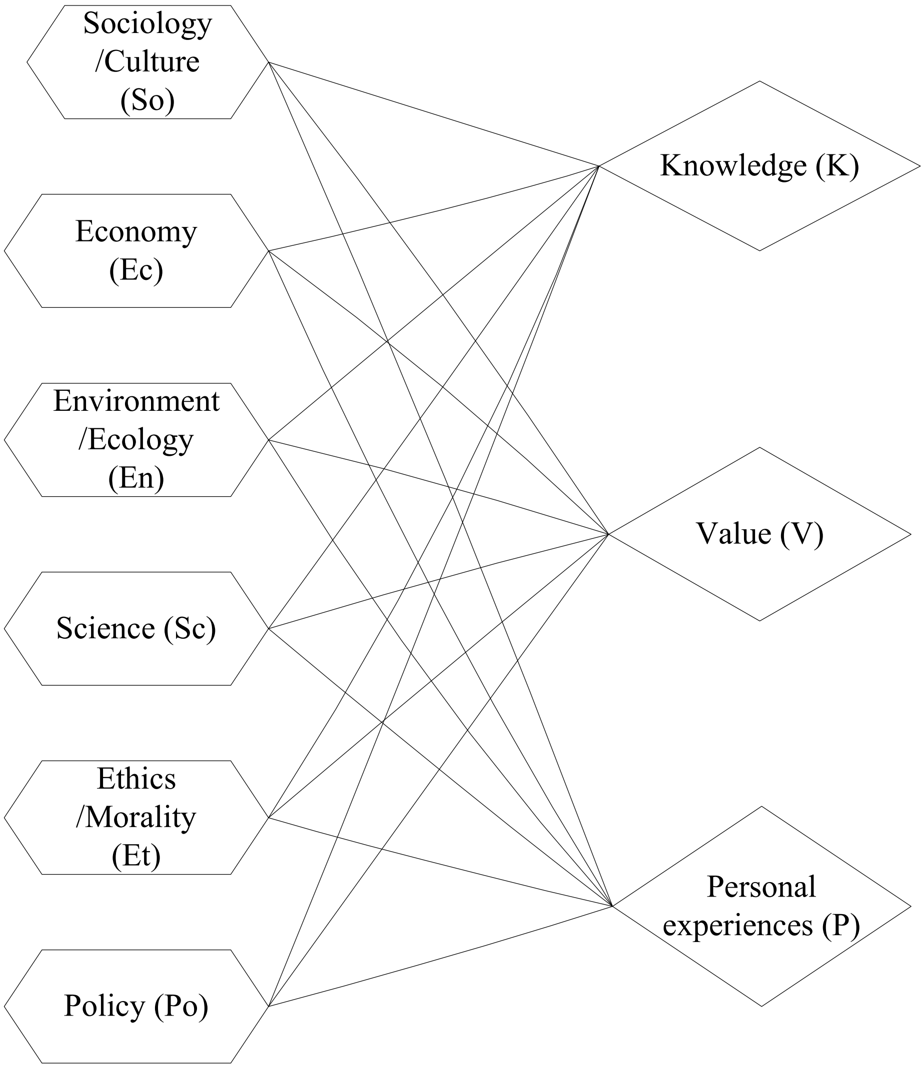
To offer a more concrete idea regarding the SEE-SEP model and also to prove that the SEE-SEP model is a workable model to represent the essence of SSIs, here, we try to provide evidence from former studies analyzed via the SEE-SEP framework.

Since there are six subject areas and three aspects forming the SEE-SEP model, we could generate 18 codes to analyze students' informal reasoning and argumentation. We added all the second characters from the six subject areas to the codes, due to there are two S and three E from the original abbreviation. Accordingly, the codes are presented in Table 1. Through Figure 3, we could visualize the analytical framework of the SEE-SEP model. The following examples for supporting the SEE-SEP model were extracted from the participants' protocols in the former studies. The specific texts related to each code are highlighted with boldface.

Table 1. *The codes generated from the SEE-SEP model.*

Aspects / Subject areas	Knowledge (K)	Value (V)	Personal experiences (P)
Sociology/culture (So)	SoK	SoV	SoP
Environment (En)	EnK	EnV	EnP
Economy (Ec)	EcK	EcV	EcP
Science (Sc)	ScK	ScV	ScP
Ethics/morality (Et)	EtK	EtV	EtP
Policy (Po)	PoK	PoV	PoP

Figure 3. *The analytic framework of SSIs.*



From Patronis et al., (1999) study, we could find some suitable evidence from students' discussion about whether they should build up a new road in the school area.

Example 1:

> *We propose the already existing road, which is along the coast, should be continued for 2 or 3 km towards Roin (a nearby village) and then turn towards the Patras-Athens Motorway. There are two reasons to support our opinion: firstly the road should be moved away from the school, and as a result* ***we will avoid accidents*** **(SoK)**, *and secondly to* ***avoid noise pollution*** **(EnK)**, *which is caused by the road being so close…and the big trucks that travel on it. (p.749-750)*

Example 2:

> *When I asked where the train will pass, Angeliki said that it will pass under the bridge. But, from what she said,* ***this means that the bridge will be long, and higher than the train rails. So, much more money will be spent.*** **(EcK)** *(p. 750)*

The following examples were analyzed from the study by Chang & Chiu (2008). From the university students' written reports arguing about four different SSI topics regarding GMO, organic food, DDT and Malaria, and Dioxin, we could also find evidence to support the SEE-SEP model via the different SSI topics conducted in this study (Chang & Chiu, 2008, p. 1766).

Example 3:

> [GMO topic] ***It is not a good idea*** *if we always follow other countries' steps. Just as the* ***proverb says, "repeating what others say is not good."*** **(SoV)** *(Student S013)*

Example 4:

> [Dioxin topic] *I consider the chemistry company as guilty, no matter whether there are veterans with cancer or not, since* ***dioxin has caused permanent harm to our environment*** **(EnK)** *and* ***we should be concerned more about all lives in our environment.*** **(EtK)** *(Student S011)*

Example 5:

> [GMO] *No harm to human now does not mean it will be no harm in the future. (***ScV** *about NOS) (Student S07)*

Example 6:

> [Organic food topic] *I would buy organic food, since* ***I have not heard*** *that* ***organic food is harmful to humans*** *during the past time. (Student S031)* **(EtP)**

Example 7:

> [Organic food topic] *I will not buy it, because* ***I have checked the price one time in the supermarket*** **(EcP)** *and* ***it is too expensive*** **(EcV)***. Also, I will buy any kind of vegetable, which has* ***passed the examination by our government.*** **(PoK)** *(Student S017)*

Another four examples from the study conducted by Sadler and Zeider (2004) about students' responses regarding whether cloning related issues are moral or not.

Example 8:

> *I don't think it's a moral issue…That's just me. That's just* ***not how I was brought up with family or my religion*** *or anything (participant 4).* **(SoP)** *(p. 12)*

Example 9:

> *You want to* ***let someone have the right to choose****. You know,* ***it is their child and they can do what they think is right.*** **(EtV)** *I mean I think it is more interesting and more how things work to see how your child does turn out. I don't think I could even fool around with anything going on with the pregnancy. (Participant 3). (p.13)*

Example 10:

> *I do not think it is moral (to employ gene therapy).* ***I do not think it is a good thing to be creating these genes*** *just to change the way individuals are. (Participant 13).* **(ScV)** *(p.13)*

Example 11:

> ***With the example of SCID, we have a disease that is killing.*** **(ScK)** *I think ethically, if this gene is found and we can replace it, I think ethically we have to replace it.* ***I think ethically we have to replace it, and we need to do so as equally and equitably as we can.*** *(Participant 17).* **(EtK)** *(p.13)*

From the same research team, another study could also provide some evidence (Sadler & Zeidler, 2005b).

Example 12:

> ***I know some families that have gone through the (Huntington's) disease process*** *and there is nothing that anyone can do except make the patient comfortable…****there is no way of preventing it unless you change the gene.*** *(H29).* **(ScP)** *(p.86)*

In one study of teaching informal argumentation regarding GMO, we could also find some examples from students' discussion and interesting questions to ask (Chang, 2007).

Example 13:

> *(S004)* ***I don't think our government is good at monitoring GMO*** *in our market, so I don't choose GMO in my life* **(PoV)*****. From TV news, one time I saw some information*** *from a western country…I forgot which country… that their* ***government*** *could monitor food in the market regularly, which is trustful for me.* **(PoP)**

Example 14:

> *(S015) Although GMO* ***can be good to our environment*** *from decreasing the use of pesticide,* ***I still could worry about*** *whether GMO will* ***cause any ecological problem*** *in the future* **(EnV).** ***Like global warming phenomenon we experience now*** **(EnP),** ***when car was invented, people didn't think about it can cause global warming today*** **(EnK).**

Overall, more examples of SSI topics and the content of peoples' arguments could be found in the cited papers and others. With the limited content of this article, we could only provide some examples to prove the usefulness of the SEE-SEP model developed here, and offer a holistic view about the essence of SSIs for further discussions on the SSI movement.

Conclusions and implications

Scientific literacy is the ultimate goal in science education, and SSIs have been indicated as a suitable context to promote scientific literacy in the globalized world of today (Chang & Chiu, 2008; Driver et al., 2000; Hughes, 2000; Kolstø, 2001; Zeidler et al., 2003; Zeidler et al., 2002). Through SSI contexts, in addition to transferring content knowledge to an authentic issue, students' abilities of critical thinking, decision making and science communication can also be promoted (Albe, 2008; Kolstø et al., 2006; Lee, 2007; Maloney, 2007). To induce students' interests about learning science, especially female students, SSI-based instruction could be considered as well (Albe, 2008; Chang et al., 2009; Sadler, 2009a). According to the important and emerging SSIs stressed by a considerable amount of literature, we hope that people could understand and remember the essence of SSIs better through the SEE-SEP model with the visualization of the benzene and diamond structures presented in this article. Educators and researchers from different disciplines and fields could also think about applying this SEE-SEP model in their practical work. For instance, teachers from different disciplines could design SSI-based instruction together and provide students with a more holistic view about different SSI topics. Meanwhile, this SEE-SEP analytical framework could also be used in evaluating whether students possess the abilities to deal with the complex and multidimensional features of SSIs, and/or could consider SSIs from different points of view. For researchers from science education, more research-based instructional design and assessment concerning SSIs and the skills of informal reasoning and argumentation could be anticipated based upon this SEE-SEP model.

Before making decisions in their work, even policy makers and scientists are also encouraged to reflect about the possible consequences from the different subject areas.

In the end, based on this SEE-SEP model, we sincerely look forward to more discussion and application in the field of interdisciplinary education for developing teaching and learning materials to enhance students' and the public's abilities to discuss SSIs and make SSI decisions.

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