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Using the SEE-SEP Model to Analyze Upper Secondary Students' Use of Supporting Reasons in Arguing Socioscientific Issues

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Abstract To achieve the goal of scientific literacy, the skills of argumentation have been emphasized in science education during the past decades. But the extent to which students can apply scientific knowledge to their argumentation is still unclear. The purpose of this study was to analyse 80 Swedish upper secondary students' informal argumentation on four socioscientific issues (SSIs) to explore students' use of supporting reasons and to what extent students used scientific knowledge in their arguments. Eighty upper secondary students were asked to express their opinions on one SSI topic they chose through written reports. The four SSIs in this study include global warming, genetically modified organisms (GMO), nuclear power, and consumption. To analyse students' supporting reasons from a holistic view, we used the SEE-SEP model, which links the six subject areas of sociology/culture (So), environment (En), economy (Ec), science (Sc), ethics/morality (Et) and policy (Po) connecting with three aspects, *knowledge, value* and *personal experience* (KVP). The results showed that students used value to a greater extent (67%) than they did scientific knowledge (27%) for all four SSI topics. According to the SEE-SEP model, the distribution of supporting reasons generated by students differed among the SSI topics. Also, some alternative concepts were disclosed in students' arguments. The implications for research and education are discussed.

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Introduction

The quality of decisions made by the public is of great importance in a democratic society, and in recent decades several science educators have emphasized the need and the significance of teaching decision-making in science education (Aikenhead 1985; Millar and Osborne 1998; Newton et al. 1999; Zeidler et al. 2005). Particularly, in this science- and technology-dominated age, many socioscientific issues (SSIs), such as global warming and energy issues, are emerging and the public's ability to provide their standpoints on SSIs attracts a lot of interest (Kolstø 2001). The notion of scientific literacy explicitly addresses the capability to make informed decisions regarding SSIs (Sadler 2004), which also has been acknowledged worldwide, e.g. the American Association for the Advancement of Science (1990), and the curriculum guidelines in Taiwan (MOE 1998) and Sweden (Lpf 94). In Sweden, the curriculum for the non-compulsory school system states that teaching in different subjects should provide pupils with a knowledge base as well as develop their ability to possess personal standpoints, particularly to make decisions on SSIs (Lpf 94). Furthermore, schools should strive to ensure that all pupils will be able to increase their abilities to formulate independent standpoints based not only on empirical evidence and critical analysis, but also on rational and ethical considerations.

The question that follows is: how to ensure the quality of decision-making? The importance of argument-based decision-making has been pointed out (i.e. Dickinson

1998), although it has been discussed that the framing of questions and people's values are also influential when making a decision (i.e. Tversky and Kahneman 1981). Furthermore, thinking, argumentation and their relationship have become the important issues in science education in order to understand how people make decisions and behave in promoting individuals' thinking skills (Chang and Chiu 2008). Namely, to make informed decisions about SSIs, an individual's skills of informal argumentation play an important role (Chang and Chiu 2008) and should be taught in school education (Driver et al. 2000). Accordingly, the focus of this study is to investigate how students use different reasons as resources to support their arguments on different SSIs.

In the following theoretical background, the definition of SSIs and the concept of informal argumentation will be described. Since the SEE-SEP model is applied as an analytical framework in this study to analyze students' use of resources in supporting their arguments on SSIs, the SEE-SEP model is delineated as well.

SSIs and Informal Argumentation

Ill-structured and open-ended controversial issues that emerge from the interrelationship of science, technology and society are termed SSIs (Chang and Chiu 2008). Society today is continuously confronted with SSIs which are connected to our life and environment and also reported in the media, and some of them are even involved in local disputes (Kolstø 2006). According to Sadler and others (Sadler 2004; Sadler and Fowler 2006; Ratcliffe 2003), SSIs are dilemmas that include both social and scientific factors; they are often related to biotechnology (e.g. cloning technology) and environmental issues (e.g. global warming) in modern society. The use of SSIs in education has focused on empowering students to handle the science-based issues that shape their current world and have a large impact on their future (Driver et al. 2000; Kolstø 2001). To face the challenges of SSIs, Sadler and Fowler (2006) indicate that school science should reflect on the dynamic interactions between science and society focusing not only on the issues behind science, but also the relationship with social, political, economic and moral challenges.

To discuss or make decisions about SSIs, there are many perspectives involved, such as the skill of informal reasoning, the concept of the nature of science, the skill of evaluating information, and the development of conceptual understanding regarding science content (Sadler 2004). SSIs, therefore, provide a good context for people to demonstrate the skills of informal argumentation (Chang and Chiu 2008; Driver et al. 2000; Kortland 1996; Zohar and Nemet 2002), in which informal reasoning serves as the core, and the performance of informal argumentation is highly related to the quality of decisions-making on SSIs (Chang and Chiu 2008). Informal reasoning involves the generation and evaluation of positions in response to complex issues, which very often lack definite solutions. Living in the modern age, people should know how to engage in informal reasoning, ponder causes and consequences, and know how to take different positions and make alternative considerations (Means and Voss 1996; Zohar and Nemet 2002). Here, it is important for us to address that informal argumentation functions as a foundation when dealing with SSIs in this study.

Concerning the skills of informal argumentation, in addition to the evaluation of an individual's own claim through perceiving the limit and extension of the claim, the number of supporting reasons is also counted (Chang and Chiu 2008; Means and Voss 1996). In this study, we aim to investigate students' use of supporting reasons in their arguments. Chang and Chiu (2008) define informal argumentation, in contrast to formal argumentation with fixed premises, as argumentation where people can provide various premises coming from their personal beliefs, knowledge and information from newspapers and textbooks or life experience as the resources of supporting reasons. However, to discuss the supporting reasons of people's informal argumentation in a holistic way, the SEE-SEP model has been developed (Chang Rundgren and Rundgren 2010) and serves as the analytical framework in this research.

The SEE-SEP Model

To date, a great body of papers have highlighted the emerging and cross-disciplinary features of SSIs, and the results imply that many dimensions are involved in the process of students' informal reasoning and informal argumentation about SSIs, such as scientific knowledge (Albe 2008; Chang and Chiu 2008; Ekborg 2008; Jallinoja and Aro 2000; Keselman et al. 2004), or a combined perspective such as individuals' personal experience, values, ethical concerns, or government policy (Chang and Chiu 2008; Fleming 1986; Patronis et al. 1999; Sadler 2004; Zeidler et al. 2002). The dimensions connected to SSIs are also being discussed from broader scales, such as Science-Technology-Society (STS) (Chang et al. 2009; Sadler 2009), sustainable development (Chang et al. 2009; Simonneaux 2001; Simonneaux and Simonneaux 2009), ethics (Sadler and Donnelly 2006; Zeidler and Keefer 2003; Zeidler et al. 2005), an ecological framework (Colucci-Gray et al. 2006), or a humanistic view (Dos Santos 2009). Although there are cross-disciplinary dimensions included in the SSI research cited above, there is an existing consensus that SSIs have four important features: complexity, multiple perspectives, inquiry and

scepticism (Albe 2008; Colucci-Gray et al. 2006; Fensham 2008; Sadler et al. 2007; Simonneaux and Simonneaux 2009). Accoridng to Sadler et al., these features have emerged from the practices for decision-making in the SSI context and ought to be addressed as citizenship goal (Sadler et al. 2007, p. 374):

1. Recognizing the inherent *complexity* of SSI.
2. Examining issues from *multiple perspectives*.
3. Appreciating that SSI are subject to ongoing *inquiry*.
4. Exhibiting *skepticism* when presented with potentially biased information.

The SEE-SEP model has been developed to integrate the cross-disciplinary dimensions and the four features of SSIs into a more holistic viewpoint (Chang Rundgren and Rundgren 2010). The name of the SEE-SEP model was taken from the abbreviations of six subject areas of SSIs regarding sociology/culture (*So*), environment (*En*), economy (*Ec*), science (*Sc*), ethics/morality (*Et*) and policy (*Po*), which are connected with the three aspects of *knowledge, value* and *personal experience* (KVP) in the SEE-SEP model. According to Chang Rundgren and Rundgren (2010), it is considered that the three aspects of KVP could be intertwined with those six subject areas (Fig. 1), i.e. people could present their supporting reasons not only from their knowledge in the subject area of science and/or economy, but also from their personal experiences in the area of environment and/or policy in their informal argumentation. Figure 1 also shows the 18 codes

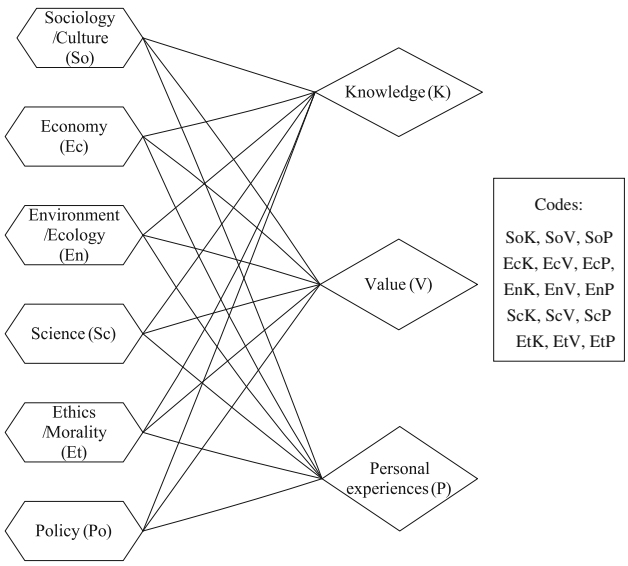

Fig. 1 The analytical framework based upon the SEE-SEP model used in this study (Chang Rundgren and Rundgren 2010). The 18 codes are generated by linking the possible combinations of the six subject areas with the aspects of knowledge, value, and personal experience

generated by the SEE-SEP model. The quote below is an example of how the SEE-SEP model links the subject area of environment (En) to the different aspects (KVP) in an argument on a GMO topic:

> *Although GMO* ***can be beneficial to our environment*** *by decreasing the use of pesticide,* ***I still could worry about*** *whether GMO will* ***cause any ecological problems*** *in the future* **(code: EnV)**. ***Like the global warming phenomenon we experience now*** **(code: EnP)**, ***when cars were invented, people didn't think about them causing global warming today*** **(code: EnK).** (Chang Rundgren and Rundgren, 2010)

In this study, the SEE-SEP model is adopted to analyze students' informal argumentation to see how students use supporting reasons in arguing about SSIs. The detailed coding scheme and the examples of each code are presented in Table 1 in the methods section.

Purpose and Research Questions

This study aims to adopt the SEE-SEP model to investigate upper secondary students' use of supporting reasons in their informal argumentation and to determine to what extent scientific knowledge was used. The research questions include: (1) How is the distribution of supporting reasons represented in students' informal argumentation? (2) Do the distributions of supporting reasons differ among the four topics of SSI? (3) Are there any alternative conceptions presented in regard to knowledge in students' informal argumentation?

Methods

In some research on investigating students' abilities to reason about SSIs, group discussion has been found useful for students to exchange and evaluate ideas from different perspectives (Kelly et al. 2001). However, other researchers warn that the social demand of the group might be influential upon the results. Problems can arise when too much of the communication is taking place in groups, e.g. people may depend on the social interaction among the group members, or not all the participants could give voice and speak their opinions (Albe 2007). Hence, instead of group discussion, we invited participants to express their opinions individually, through written reports, on one SSI topic of their choice. The reason why we let students to choose one of the SSIs to argue in this study was that we wanted students to argue something that they were interested in. This is also a situation they are familiar with, since in national tests in Sweden, students are often asked to choose one of several topics.

Table 1 The definitions of the codes and examples from students' writings

Codes	Definitions	Examples
SoK	Students provide concepts or theory from sociology/culture to support their arguments	273FSP3Tg: to produce ethanol they must devastate the rain forest which destroys nature and this also causes poor people in underdeveloped countries great problems since they rely on the rainforest for their incomes. (in combination with EnK)
SoV	Students make connection of value/affection/attitude from the subject area of sociology/culture	194MSP3Tg: we, in the developed countries just keep on letting our consumption rate go up, and this is not a healthy thing
SoP	Students use their personal experiences from the subject area of societies or cultures to support their arguments	044FNV3Tg: if I, a poor student, can afford to buy ecological food and organic cotton clothes, then everybody else in Sweden can do that too
EcK	Students provide concepts or theory from economy subject area to support their arguments	314MSP3Tg: people who go shopping like to buy the cheapest items available and the companies know this and try to keep their costs as low as possible to handle the competition with other companies
EcV	Students make connection of value/affection/attitude from the subject area of economy	084FSP3Tg: but I don't believe that we should stop consuming completely because this creates wealth for poor countries, and strengthens their economy
EcP	Students use their personal experiences of economics to support their arguments	211FNV3Tg: I don't buy ecological and locally produced food very often since it's more expensive and I can't afford it
EnK	Students provide concepts or theory from ecology/environmental science to support their arguments	273FSP3Tg: to produce ethanol they must fell all trees in the rain forest which destroys nature and this also causes poor people in underdeveloped countries great problems since they rely on the rainforest for their income. (In combination with SoK)
EnV	Students make connection of value/affection/attitude from the subject area of ecology/environmental science to support their arguments	164FSP3Tg: I believe that we, consumers, have a great responsibility regarding the environment, to keep the air, water and land clean and that we need to change our attitude towards buying clothes, food etc.
EnP	Students use their personal experiences of ecological/environmental science to support their arguments	261FSP3Tg: I used to believe that all global warming was just crap, but since I've seen Al Gore's movie "An inconvenient truth" and all facts in it I believe that we really need to do something to stop it
ScK	Students provide concepts or theory from science (i.e. biology, chemistry, technology, medicine and so on) to support their arguments	382FSP3Tg: scientists have made a type of rice called the golden rice, that contain beta carotene and protein which is not included in regular rice
ScV	Students make connection of value/affection/attitude from the subject area of science to support their arguments	393FNV3Ag: I feel totally safe about how they handle the nuclear power plants here in Sweden; they have so many controlling systems making sure that there cannot be any meltdowns, and have no fear for any accidents
ScP	Students use their personal experiences from the subject area of science to support their arguments	101FNV3Tg: I've learned in school that we have very little knowledge about how different things affect the environment and what we could do to lower the CO_2 emissions which would make the global warming less aggressive
EtK	Students provide concepts or theory of ethics/morality to support their arguments	024FSP3Tg: it is often the people in poor countries who have to work hard for little money to produce all the stuff that we want to buy
EtV	Students make connection of value/affection/attitude from the subject area of ethics/morality to support their arguments	074FSP3Tg: if we don't buy any clothes at all it would affect children all over the world whose parents will lose their work, and that would be terrible
EtP	Students use their personal experiences of ethics/morality to support their arguments	034FSP3Tg: I have read and heard of many enterprises that use child labor in their production to keep the costs as low as possible

Table 1 continued

Codes	Definitions	Examples
PoK	Students provide concepts or theory of policy to support their arguments	362MNV3AG: in order for GMO to be sold here (in Europe) it must be approved by the EU and they have a very restrictive policy on GMO
PoV	Students make connection of value/affection/attitude from the subject area of policy to support their arguments	374FSP3Tg: there should be laws making the producers obliged to be environmentally friendly and those who break the law should have to close their businesses
PoP	Students use their personal experiences from the subject area of policy to support their arguments	203FNV3Tg: we used to have a law forbidding development of nuclear power and my own mum has told me how they fought to get rid of all nuclear power, and if it had not been for the alternative "don't know" in the election, she says they would have won

Participants

There were two upper secondary schools invited to participated in this study and they are both located in a medium-sized town in Sweden. A total of 80 students, 58 females and 22 males, participated in this study (age 18–19). The study was performed during the last month of upper secondary school period (before graduating). Since the influence of study backgrounds was not the focus of this study, but to prevent the bias caused by the students' study backgrounds, we planed to make science and social science majors equally involved in this study with 40 students enrolled from a science major program and another 40 students from a social science program. The students from the science program had taken courses in chemistry, biology, physics and mathematics to a great extent as well as a mandatory general science course. The students from the social science program had not studied as much mathematics and less chemistry, biology and physics than the science majors. Both groups of students had taken the mandatory general science course (which includes topics like ecology, energy and environmental science) for one semester (equal to 38 teaching hours) during their upper secondary school years. All students were informed about the purpose of the study and joined voluntarily. Some of the students were aware of that the first author is a science teacher, but not the others. The data was collected in a classroom setting, not specifically in the science classroom.

The Development of the Instrument

In most of the previous research regarding argumentation about SSIs, students were given some extended information about the SSIs (Sadler 2004), but in this study, our interest lies in students' performances without any background information provided by the researchers. In other words, we hoped to probe students' informal argumentation through an authentic context.

The four SSIs addressed in this study were related to the notion of sustainable development, including global warming, nuclear power, genetically modified organisms (GMO) and consumption. Although some of these topics have been used by other researchers in their earlier work (Chang and Chiu 2008; Sadler and Fowler 2006; Sadler and Zeidler 2005), these topics are still of great importance with an ongoing debate in both the local and international press. Besides, these topics had been included in the participating students' courses during their upper secondary school years. In this study, all students were asked to state their opinions, make arguments and motivate themselves as clearly as they could with regard to the SSI to which they chose to respond. The instrument presented below is the four SSI topics used in this study, translated from the Swedish version. A pilot study has been conducted to confirm that the instructions of the SSI topics were clear for upper secondary students.

Topic 1: Global Warming

There has recently been a debate on whether global warming depends on anthropological factors or if it is due to natural processes. Do you believe that climate change is due to natural processes or to human activities? Please state your opinion in writing as clearly as possible, and try to make your arguments the best you can.

Topic 2: GMO

GMO (genetically modified organisms) means genetically modified plants, animals and microorganisms. They have had their genes changed by using methods that do not exist naturally. Genetically modified agricultural plants are, since the end of the 1990s, common in North- and South America, where much of the soy, corn and cotton is genetically modified. In the rest of the world, GMO-"farming" is very small. Do you agree that GMO should be

allowed to be produced and sold? Please state your opinion in writing as clearly as possible, and try to make your arguments the best you can.

Topic 3: Nuclear Power

According to the new energy agreement made by the current national government, Sweden is going to keep on getting much of its energy from nuclear power. The law that stated that all nuclear power in Sweden was to be terminated has recently been changed so that it will now be possible to build new reactors, which has been forbidden since 1980. Do you agree that Sweden should invest in developing nuclear power as a source of energy? Please state your opinion in writing as clearly as possible, and try to make your arguments the best you can.

Topic 4: Consumption

Our way of consuming for example clothes and food have an impact on the environment and society, both on a local and a global level. Some people believe that our consumption is far too excessive and that it affects the environment in a negative way, others state that consumption is the best way to increase trade which creates welfare and stimulates the development of environmentally—sound technologies. What are our responsibilities as consumers, according to you? Please state your opinion in writing as clearly as possible and try to make your arguments the best you can.

Data Collection

Initially, the SSIs used in this research were briefly introduced by the first author to the students, and then no other information was provided, except when necessary to ensure that students understood the questions shown on the instrument. Then, students were asked to choose one of four topics and express their arguments individually through written reports. Reports were written in classroom settings, and there was no time limit for students to accomplish the task. The time used by students was approximately 30 min. The written texts were transcribed and analysed through MAX-QDA (2007) and Excel (2007) programs.

Data Analysis and the Analytic Framework of This Study

As mentioned before, this study aims to investigate students' use of supporting reasons in their informal argumentation with a focus on how much scientific knowledge that was involved. According to Chang Rundgren and Rundgren (2010), there are multi-dimensional perspectives involved in various SSIs and found in students' arguments regarding SSIs.

To analyze students' written reports, the unit used for coding is sentence-based. The definitions and examples of the SEE-SEP analytical framework are presented in Table 1. Concerning the validity and inter-rater reliability, seven other science educators were invited to validate the coding scheme. Three of them were experienced science teachers and also science education researchers with around 2 years' experience in qualitative and science education research, and the other four had more than 6 years' science teaching experience. Initially, the definitions and explanatory examples of the SEE-SEP model presented in the published article (Chang Rundgren and Rundgren 2010) were introduced by the first author to the other seven science educators, and then a discussion of the coding scheme followed. A total of ten students' written reports were randomly selected and analysed by the first author first to ensure that all 18 codes of the SEE-SEP model (Fig. 1) were present, and then the same ten reports were given to the seven invited science educators to do the coding individually. The coding results of the ten students' written reports were then checked and discussed individually.

Based upon the concept of joint-probability of agreement (Uebersax 1987), the inter-rater reliability was counted through the agreeable codes divided by the total codes (of agreeable and disagreeable ones) generated by the first author and the other seven science educators, and then an average score was counted. The inter-rater reliability was 0.95 presenting a high agreement and understanding about the SEE-SEP analytical framework among the science educators. Concerning the codes which caused disagreement, after being explained and discussed individually by the first author with the other science educators, a consensus was achieved. Table 1 shows the consensus of the coding scheme and the related examples.

Results

According to the SEE-SEP analytic framework, we have analysed 80 students' written reports through the 18 codes presented earlier. We found that global warming was the most chosen SSI topic (26 students, 33%), and the second most chosen SSI topic was consumption (25 students, 31%). The topic of nuclear power was chosen by 18 students (23%), and only 11 students (14%) chose to argue about GMO. Following from this, the distribution of the supporting reasons analyzed via the SEE-SEP model is reported by SSI topic, and the distribution is counted by dividing the numbers of students chose to argue in each

topic. Some alternative conceptions we found in students' informal argumentation are also shown in this section.

The Distribution of Students' Supporting Reasons Based Upon the SEE-SEP Model Framework

As mentioned previously, the SEE-SEP model was adopted to analyse students' written reports, and we present our findings based upon the 18 codes presented earlier. All of the 18 codes were found among the 80 students' written reports, although no single report contained all 18 codes. Combining all the students' results in arguing the four SSI topics, we found that the subject area of environment/ecology connecting to the aspect of value (EnV) was the most common code found among students' supporting reasons (17.5%); the second most common code was ethics/morality connected to value (EtV) at 16.1%. Another two codes, ScV, and SoV, were 15.1 and 13.3% respectively. The code SoK was used to an extent of 13.3%, and ScK was 11.7%. ScP was used to an extent of 0.5% only, and the subject area of economy related to personal experience (EcP) was 0.8%. EtP was used to the extent of 0.9%. The least used (0.1%) of the 18 codes found among students' supporting reasons was the subject area of policy related to both of the aspects of knowledge (PoK) and personal experience (PoP).

The Distribution of Knowledge, Value and Personal Experience

To emphasize students' use of KVP, Fig. 2 shows the comparison among these three aspects from all the 80 students' informal argumentation on the four SSI topics. Our results showed that knowledge and personal experience were used to a lower extent (27 and 6% respectively) than were values (67%) in students' arguments.

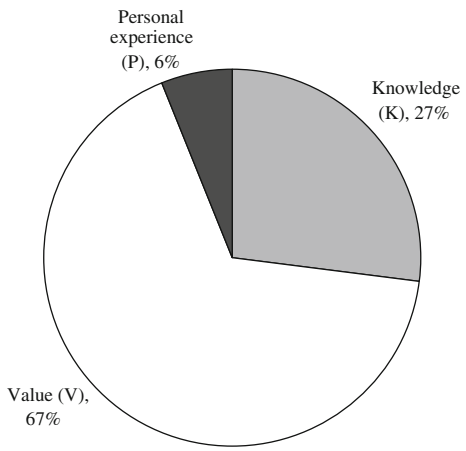

Fig. 2 The average distribution of KVP found in all the 80 students' arguments on the four SSI topics

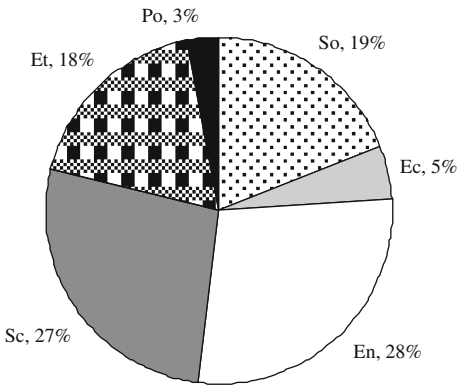

Fig. 3 The average distribution of six subject areas students applied in their arguments on the four SSI topics

The Distribution Among Six Subject Areas of the SEE-SEP Model

When only looking at all students' use of the subject areas of sociology/culture, economy, environment/ecology, science, ethics/morality and policy (Fig. 3) in all the four SSI topics, it was found that students applied more reasons from the subject areas of environment/ecology (28%) and science (27%) in their arguments. The subject area of sociology/culture was used to an extent of 19% and ethics/morality area was 18%. The area of economy was used by the students at a rate of only 5% and the least used was policy subject area, at a level of 3%.

The Distribution of Supporting Reasons Among the Different Topics of SSI

After considering that the students' choices of SSI topics might influence the aforementioned results of the distributions of reasons, it is important to analyse our data in depth to see how the distribution of reasons differs with respect to the four different SSI topics individually to answer research question 2 of this study.

In terms of the students' use of the three aspects of KVP when making arguments on the different SSI topics, it was discovered that students' use of the value aspect was to the same extent (67%) regardless of which SSI topic was chosen. The aspect of knowledge was used to an extent of 23% in the topic of consumption, 27% in the topic of global warming, 31% in the topic of GMO, and 32% in the topic of nuclear power. From the results of the students' written reports, personal experiences were used as supporting reasons to an extent of 10% in the topic of consumption, 6% in arguing global warming, 2% in the topic of GMO, and only 1% in the nuclear power issue (Fig. 4).

Concerning students' use of the different subject areas of SEE-SEP model among the different SSI topics (Fig. 5),

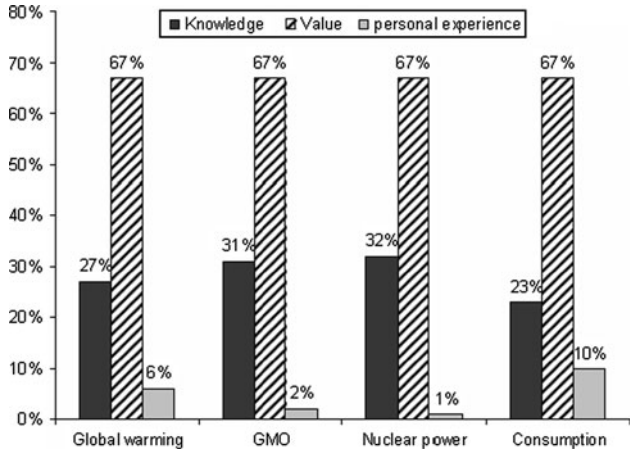

Fig. 4 Students' use of KVP in the different SSI topics

in the topic of global warming they applied the subject area of sociology/culture to an extent of 17%, economy was 1%, environment/ecological was 39%, science was 19%, ethics/morality was about 23% and policy 1%. In the GMO topic, students used the subject area of sociology/culture to an extent of 11%, economy was just 1%, environmental/ecology was about 13%, science was higher, 61%, ethics/morality was 9% and policy was only 5%. Regarding the nuclear power topic, the subject area of sociology/culture to an extent of 3%, economy was 4% only, environmental/ecology was about 24%, science was higher to a level of 64%, ethics/morality was about 3%, and policy was only 2%. When students argued about the consumption topic, the subject areas of sociology/culture to an extent of 30%, economy was 10%, environmental/ecology was a bit lower than sociology/culture to 26%, science was only 4%, ethics/morality was the same as environmental/ecology as 26%, and policy was the same as science at about 4%.

The Use of Knowledge in Students' Informal Argumentation

To focus on how knowledge was used by students in relation to the different SSI topics, we found that the SSI consumption topic generated knowledge of sociology/culture the most (5%), compared to the other three SSIs, which were all about 2%. Knowledge from the subject area of economy was used in the students' arguments to an extent of 4% on the topic of consumption, 2% on the SSI about nuclear power, and was not used at all by the students who had chosen to argue on the SSIs about global warming and GMO. Environmental knowledge was used by the students in arguing on the SSI about global warming to an extent of 11%, nuclear power was 10%, consumption was 9%, and GMO was about 2%. Scientific knowledge was used to an extent of 26% by the students arguing on GMO topic, 18% in the arguments about nuclear power, 14% was shown in the topic of global warming and 2% was in the consumption topic. Knowledge from the subject area of ethics/morality was used by students in justifying their arguments about consumption to an extent of 3%, GMO was only 1%, and not used at all when arguing about global warming and nuclear power. Knowledge from policy subject area was used to an extent of only 1% by the students who had chosen to argue about the SSI concerning GMO and not used at all regarding the other SSI topics. Figure 6 shows the detailed distribution.

The Alternative Conceptions Shown in Students' Supporting Reasons

It was interesting to find that some knowledge students used in their arguments might be a kind of alternative conception. Accordingly, the alternative conceptions were

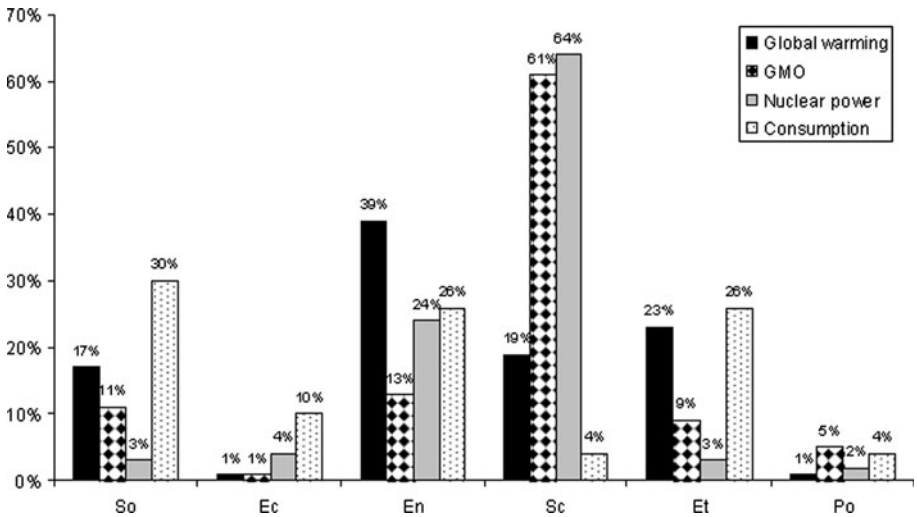

Fig. 5 Students' use of different subject areas in arguing different topics of SSI. (Sociology/culture: So, economy: Ec, environment/ecology: En, science: Sc, ethics/morality: Et, policy: Po)

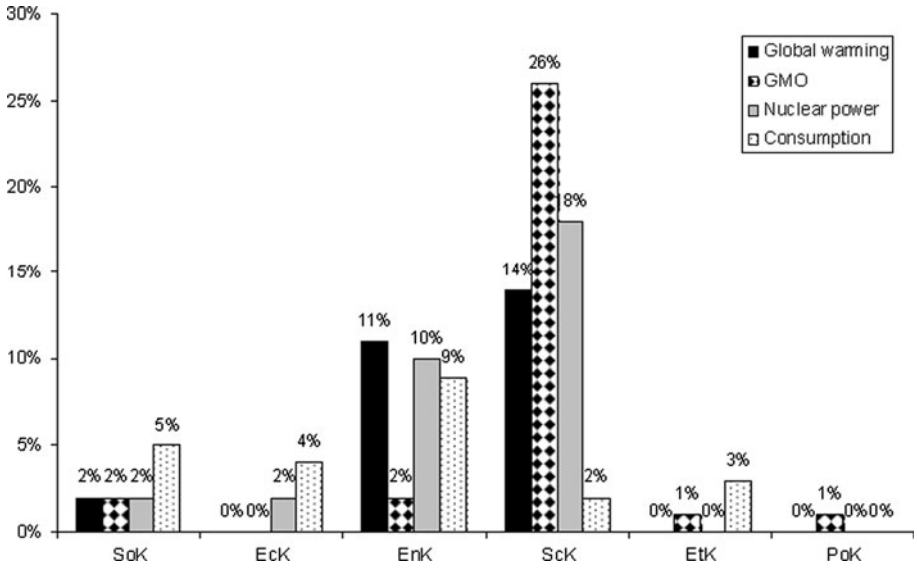

Fig. 6 Students' use of knowledge connecting the different subject areas of SEE-SEP among the four SSIs. (Sociology/culture: So, economy: Ec, environment/ecology: En, science: Sc, ethics/morality: Et, policy: Po)

probed through the code ScK (in the subject area of science connecting to the aspect of knowledge).

A student (181FNV3Tg) who chose to write on the SSI about global warming began her reasoning with the statement *We still haven't agreed on what causes global warming…… and even though we have more and more natural disasters, e.g. tsunamis and earth quakes caused by the heating of earth's atmosphere, people still don't want to do anything to prevent global warming.* This student made a statement that global warming is caused by the same phenomena as earth quakes and tsunamis, which is incorrect. Global warming is a phenomenon that takes place in the atmosphere while earthquakes and tsunamis are caused by changes in the earth's crust.

Another student (051FNV3Tg) mentioned in the same topic of global warming that *We all know that the emissions of carbon dioxide and methane gas make the ozone layer thicker which makes the sun radiation trapped within the earth's atmosphere and consequently heats the earth.* In this case, the student believed that emissions of carbon dioxide and methane gas can be transformed into ozone and make the ozone layer thicker, when in fact it is a reaction between an O_2 molecule and a single O atom that under the influence of solar radiation that forms ozone.

Another student (102FSP3Tg), when arguing on the topic of GMO, did not understand why there is a debate going on about GMO at all and wrote that *Humans have always modified and made genetic crossing on crops and domestic animals, there is nothing new to GMO*. The student in this case could not differentiate between traditional agricultural practices to produce better crops and the new bioengineering techniques applied in GMO.

Conclusions and Discussions

In order to achieve the goal of scientific literacy, the ability to make informed decisions regarding SSIs is of great importance (Sadler 2004). Preparing pupils to make informed decisions is also recognized worldwide, i.e. the American Association for the Advancement of Science (1990), and the curriculum guidelines in Taiwan (MOE 1998) and Sweden (Lpf 94). This study aimed to investigate, via the SEE-SEP model, how supporting reasons were distributed in students' informal argumentation, and to what extent students could apply their scientific knowledge to argue about SSIs. The results showed that the two topics chosen most by students were global warming (33%) and consumption (31%), which are issues frequently debated in schools and in the media. There were not many students who chose to argue on the topics of nuclear power and GMO in this study, although nuclear power is an issue currently being debated in the media because the Swedish government plans to continue using it. It appears, therefore, that media coverage may not be the main reason students chose to argue about a particular SSI, so it is of interest for future work to conduct interviews to understand the reasons why students chose specific SSIs to argue.

The results of this study have shown that the SEE-SEP model is a suitable analytical framework to analyse students' informal argumentation, since all of the 18 codes could be found among students' supporting reasons about the four SSI topics. We have also shown that the students participating in this study could use many different resources in their informal argumentation. The resources covered all the six subject areas of sociology/culture, economy, environment/ecology, science, ethics/morality

and policy, connecting to the three aspects of knowledge, value and personal experience. We discovered that the value aspect was the supporting reason used most (67%), and knowledge was only about 27% (Fig. 2). This is in line with the results of other research in science education (Grace and Ratcliffe 2002; Jiménez-Aleixandre and Pereiro-Muñoz 2002). Although the data collection was in a classroom setting, it seems that students did not try to generate more knowledge in their informal argumentation, but genuinely expressed what their ideas were. Research has revealed that students appear to view science as a body of uncontested knowledge, and they show little awareness of the tentative nature of some scientific knowledge (Lewis and Leach 2006). This might be one reason why students applied science knowledge in arguing SSIs to a lesser extent in this study, which needs to conduct interviews to understand students' choices in the future. This result also indicates that science educators need to endeavour to address evidence- and knowledge-based teaching in school education. In school education, it is important to let students have the opportunity to transfer what they have learnt from school to a daily-life context, and SSIs are suitable contexts to make such connections for students (Chang and Chiu 2008; Driver et al. 2000; Kortland 1996; Zohar and Nemet 2002). Our results also showed that only 6% of the recourses used by students were connected to personal experience. It could be because students might not be used to referring to their own experience when making arguments, or because they might not have had any experience in relation to those SSI topics in this study.

When considering students' performances on individual SSI topics, it was interesting to see that the value aspect was applied to the same degree (67%) in all four topics (Fig. 4). Students could apply more knowledge in discussing GMO and nuclear power topics, but less in global warming and consumption topics. Comparing to the results regarding students' choices of SSI topics, it seems that a student's choice of a SSI topic is not related to the degree of background knowledge they could associate with it. According to the same result (Fig. 4), students used more personal experience in the topics of consumption (10%) and global warming (6%), which may imply the degrees of familiarity among students and these SSI topics. Science was the subject area students applied in their informal argumentation at most on the topics of nuclear power (64%) and GMO (61%) (Fig. 5). The topic of global warming was argued more based upon the subject area of environment/ecology (39%). The consumption topic showed about 30% reasons from sociology/culture and showed the same percentages of 26% from both areas of environment/ecology and ethics/morality. These results supported the idea that the different attributes of SSIs could retrieve students' supporting reasons from different subject areas (Chang and Chiu 2008). The same conclusion could be seen through the analysis of the knowledge aspect (Fig. 6). It demonstrates the importance of choosing SSI topics in science teaching, especially when teachers want to engage knowledge in promoting students' abilities of informal argumentation, since different SSI topics could retrieve scientific knowledge from various subject areas to a different degree. For example, in the course of environmental sciences, using global warming and nuclear power topics could connect to scientific knowledge from both sciences and environment. Choosing a GMO topic might generate more knowledge from sciences (molecular biology and biochemistry). However, if teachers want to engage the sociology/culture area in arguing SSIs, consumption could be a good choice.

In addition, the subject areas not presented in students' informal argumentation in relation to the four SSIs should be addressed in school teaching. For example, in the SSI about GMO students used resources from the subject area of ethics/morality to a low extent (9%). The Swedish curriculum (Lpf 94 1994) explicitly states that the students should be able to discuss the possibilities and risks associated with gene technology including an ethical perspective. The SEE-SEP model can make the teacher aware of the missing aspects of students' argumentation, and further on, achieve the objectives and reach desirable outcomes of the teaching. The promotion of an individual's ethical concern regarding SSIs has been noticed and stressed in science education (Sadler and Donnelly 2006; Zeidler and Keefer 2003), and our results show that students could connect ethics/morality to the value aspect, but less to the knowledge aspect.

In this study, we also found some alternative conceptions presented by students, which indicates that teachers need to be aware of the knowledge students' use in their arguments. Sometimes students could just "cite" the scientific terms in their communication, but they do not show a deeper understanding, e.g. when a student mentioned that global warming could cause earth quakes and tsunamis.

It is not possible for school science to teach students all the science that an individual might need in their lifetime. Using SSIs as a context, however, could help to make students more engaged in science learning and better prepared for making informed decisions after school life. Although the results of this study showed that the 18 codes of the SEE-SEP model could be found among students' informal argumentation on four SSIs, none of the students could cover all the perspectives when presenting their arguments. Accordingly, it is difficult for individuals to make arguments based upon a holistic view. Similar results were found in an investigation of students' skills of informal argumentation (Chang and Chiu 2008). Hence, adopting the SEE-SEP model in teaching SSIs is applicable

to not only make teachers from different subject areas work together, but also to help students to better perceive a multidisciplinary viewpoint (Chang Rundgren and Rundgren 2010).

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