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Students' use of Justifications in Socioscientific Argumentation

Abstract

Research focusing on students' argumentation in socioscientific issues (SSI) shows that students tend to base their arguments on values rather than knowledge. This study explores Swedish upper secondary chemistry students' written argumentation. The data consists of student texts written at the end of an intervention designed to develop skills related to high quality argumentation. The results show that after being taught about argumentation and the context of SSI, students mainly base their arguments on content knowledge. Value justifications are present in students' texts, but constitute a smaller proportion. Beside content knowledge- and value justifications, we found a third category – "reasoning" – in which students draw conclusions, or make predictions of future events, to support or refute a claim. The justifications in the argumentative texts include a breadth of subject areas in which chemistry knowledge plays an important role. This study suggests that content knowledge constitutes an important part in student argumentation.

INTRODUCTION

As citizens in a democratic society, individuals occasionally need to discuss or take a stand in societal issues where scientific knowledge is needed. Participation in such "socioscientific issues" (SSI) require the use of "socioscientific argumentation" (SSA), both of which may be simulated in educational settings in order to put science content into a meaningful and relevant context (Sadler, 2009) or to prepare students for citizenship (Sadler & Zeidler, 2005). SSA tasks are generally regarded as complex and cognitively demanding for the students, for instance, because many SSI are related to a variety of different subject areas (Ratcliffe & Grace, 2003) and because students need to construct evidence-based arguments (Cho & Jonassen, 2002). Therefore, in order to help students gain a deeper understanding of a given SSI, Chung, Yoo, Kim, Lee, and Zeidler (2016) point to the importance of supporting science students' use of evidence-based reasoning, and Sadler and Donnelly (2006) stress the importance of teacher guidance.

Given the complexity of SSI and SSA, science teachers may feel insecure and reluctant when it comes to including such topics in their teaching (Ekborg et al., 2012). Teachers may also circumvent the inclusion of SSI and SSA in fear of focusing less on the scientific content (Ekborg, Ottander, Silfver, & Simon, 2013; Hodson, 2013). Studies investigating students' SSA lend support to this apprehension by showing that students tend to base their arguments on values rather than knowledge (Christenson, Chang Rundgren, & Zeidler, 2014; Lee, 2007).

The above-mentioned problems indicate a need to develop strategies for how to approach SSA in science education. For example, Christenson and Chang Rundgren (2015) have developed an assessment framework to help teachers recognize, and communicate, quality criteria in students' SSA. The framework may serve as scaffolding support for both teachers and students during the argumentative process, as it points to important aspects to consider. According to Christenson and Chang Rundgren (2015), SSA requires knowledge about the subject (content) as well as knowledge about how to construct good arguments (structure), and the framework illustrates both of these dimensions. However, due to the complexity and cognitively demanding nature of both SSI and SSA, teachers should engage with the framework during the argumentative process in order to aid the students in understanding "the art of argumentation". Therefore, in this study, we implemented an intervention aimed at guiding students in the argumentation process so that they could construct high-quality arguments. Introducing the framework to students enables teachers to communicate, for instance, the difference between value justifications and content knowledge justifications. By making students aware of expectations surrounding SSA, both with regard to content and structural aspects, teachers can help them improve their argumentation.

SOCIOSCIENTIFIC ARGUMENTATION

Studies investigating SSI-based teaching show several gains, including student learning of science content (Sadler, Romine, & Topçu, 2016; Venville & Dawson, 2010). For example, in a study by Ekborg et al. (2013) investigating teachers' experiences of working with SSI, teachers found that students not only learned scientific facts but also improved their critical thinking and ability to search for information. Furthermore, the students developed an understanding of how to use scientific knowledge in their argumentation.

However, there are also some difficulties related to SSI-based teaching. For example, in a study by Chang and Chiu (2008), students had difficulties presenting counterarguments and evaluating others' arguments. Lee (2007) investigated students' decision-making skills and their use of evidence in an SSI of whether to ban smoking in restaurants. Students in this study had difficulties distinguishing between acceptable and unacceptable evidence, and they ascribed different degrees of importance to different arguments that were not always consistent with the evidence. Further, the students in Ekborg et al.'s (2013) study had difficulties with formulating questions, critically examining arguments, and using media to find more information about the SSI. They did not learn as much science as they did during ordinary lessons. However, according to the authors, the students may not have been given enough support when formulating questions and critically examining media, which could explain their lack of learning gains.

Some of the problems presented above concern the structure of argumentation, the handling of evidence, and media literacy (i.e. searching for and evaluating information). Consequently, previous research recommends, for example, that SSI-based teaching should highlight the structural dimensions of argumentation, as this could help students understand the advantages and disadvantages of their arguments (Chang & Chiu, 2008). In an intervention study by Zohar and Nemet (2002), students who received guidance in relation to both content knowledge and argumentation skills showed significant gains in both areas. The control group only received instruction concerning the content, and they showed no improvement in argumentation skills. These findings suggest that more content knowledge does not, in itself, lead to a higher quality argumentation. On the contrary, there is an obvious need for supporting the argumentation process as well. Despite this need, few authors have suggested specific ways for teachers to support students' argumentation.

Knowledge and values

Well-grounded SSA requires both scientific knowledge and values. Scientific knowledge is needed to understand the underlying issues, to make informed choices, and to argue for ones' point of view (Hodson, 2013). However, decision-making cannot be based solely on knowledge. Decisions must also be grounded in values, since SSI always contain some kind of moral considerations (Chang Rundgren & Rundgren, 2010; Sadler & Donnelly, 2006).

Nevertheless, problems may arise when values are given too much space to the detriment of knowledge. For example, Christenson et al. (2014) investigated upper secondary school students' written argumentation using the so called "SEE-SEP model" (Chang Rundgren & Rundgren, 2010) in four different SSI-cases and concluded that students tend to use values rather than knowledge to support their arguments. This was true for all four SSI topics, but the use of knowledge varied slightly, from 22 to 34 per cent (Christenson et al., 2014). Importantly, the cases were performed without any beforehand preparations by the students, although the topics were chosen according to what the students ought to have learned in previous courses. Another example is Sadler and Donnelly's (2006) study, where high-school students who participated in an SSI argumentation regarding genetic engineering problems did not use content knowledge to any notable extent, instead perceiving the SSI as moral problems.

Some conclusions and implications from the studies described above are relevant to the current study. For example, several participants in the study by Sadler and Donnelly (2006) expressed that they might have done better if they knew more about the circumstances surrounding the issues. Therefore, students' difficulties with presenting valid arguments might not be about lack of content knowledge but about lack of context. Accordingly, if students do not have an adequate understanding of the context, more content knowledge does not necessarily help. The reverse could also be true: context-specific knowledge depends on a strong content knowledge. Both content and context-specific knowledge seem to be needed in order to fully grasp the complexity of an SSI and to view the issue from different perspectives (Hodson, 2013; Sadler & Donnelly, 2006). Altogether, to enhance the quality of students' argumentation, teachers should provide opportunities for the students to understand the complexities underlying the SSI, not just the basic concepts related to it.

In addition to content and context-specific knowledge, students also need to learn structural knowledge about how to formulate an argument – such as argumentation structure, the status of evidence, and coherence of claims – in order to understand "the art of argumentation" (Sadler & Donnelly, 2006). The Swedish science curricula (SNAE, 2011) already emphasizes SSA, suggesting that students should be encouraged and given opportunities to practice their argumentation skills (Christenson et al., 2014).

Argumentation framework

Research about argumentation often uses Toulmin's (2003) argumentation pattern (TAP), which includes data, warrant, backing, qualifiers, claim, and rebuttal. The SEE-SEP model by Chang Rundgren and Rundgren (2010) is another model that connects knowledge, values, and personal experiences to six different subject areas (e.g. Science, Economy). From these models, Christenson and Chang Rundgren (2015) have designed a framework to help teachers assess students' argumentation in SSI. They have also reviewed research on SSA to find elements that are considered to be of high quality. This resulted in two categories: qualities related to *structure* and *content*. Important aspects of the structure category are presenting justifications for a claim and including counterarguments in which other perspectives are considered. Quality indicators related to the content category are presenting data and content knowledge supporting the claims and considering the relevance and correctness of the content knowledge. Values and moral reasoning (which should be grounded) can also improve the quality of an argument.

Intervention studies

As noted above, despite the apparent need for supporting students' argumentation, few authors have suggested specific ways for teachers to provide such support. Findings from some of the exceptions are presented below.

In an intervention study by Lee (2007), students were guided towards informed decision-making by being presented with all the information they needed in order to construct their arguments. The students were also guided by questions in the argumentation process. However, the students were not specifically taught how to construct arguments. Furthermore, the SSI focused on health aspects and students' values and did not take other aspects (e.g. environmental effects or arguments related to economy) into account, thereby reducing the complexity.

In Venville and Dawson's (2010) study, students were specifically taught about argumentation during one lesson, followed by two lessons of whole-class discussions. The results show that students were able to produce more rational arguments (according to TAP) after the intervention. However, the authors point to limitations regarding the methods used to analyse data. For example, they did not consider the scientific accuracy of the data, claims, and warrants presented by the students. Therefore, the arguments may have been scientifically inaccurate or irrelevant but still classified as "rational and complex" (regarding argumentation structure).

Yet another example of explicit teaching of argumentation is provided by Zohar and Nemet (2002). In their study, students' written arguments were guided by questions about the reasons for their decisions, counterarguments, and rebuttals. This study also encompassed a more extensive intervention (12 hours), including discussions in smaller groups, whole-class discussions, and individually written assignments. The analysis of students' argumentation focused on the presence and number of justifications given for arguments, counterarguments, and rebuttals. However, the kind of justifications the students presented (e.g. knowledge, values, or subject area) was not analysed, except for the use of content knowledge in relation to genetics.

In summary, there are notable limitations in relation to the studies described above. First, the complexity of the SSI (for example, arguments from different subject areas or perspectives) has not always been taken into account. Second, whether arguments are based on correct and relevant information or not has also not always been considered. Finally, the topics chosen for the SSI are most commonly connected to biology and physics (cf. reviews of research on SSI, e.g. Sadler, 2004), such as global warming, energy, GMO, and cloning.

AIM AND RESEARCH QUESTIONS

Teaching students "the art of argumentation" is an important aspect of preparing them for citizenship, but SSI and SSA are complex and cognitively demanding tasks. Hence, previous research has pointed to the importance of teacher guidance during the argumentation process. However, there are several limitations to previous research, such as not taking the complexity of the SSI, or the correctness of students' arguments, into account. There also seems to be a predominance of SSI interventions in relation to biology and physics, with fewer examples from chemistry.

Thus, this study aims to investigate students' written argumentation about an SSI focusing on per- and polyfluoroalkyl substances (PFAS) in everyday products, where the complexity of the SSI is taken into account by considering arguments from several different areas (e.g. environmental and economic), as well as including the correctness and relevance of students' arguments. Furthermore, the argumentation will be analysed after the students have gone through a series of lessons designed to support the development of skills related to high quality argumentation, as suggested by Christenson and Chang Rundgren (2015). Therefore, an additional aim is to provide knowledge about how to support the implementation of SSI-based science teaching. Specifically, the study aims to answer the following questions:

- How do students support their claims in an SSI, after participating in an intervention focusing on SSA?
- Which subject areas are represented in students' justifications within the SSI of PFAS in everyday products?

METHODS

This is an intervention study in which the intervention consists of a teaching sequence focusing on teaching SSA to the students. The participants were 24 students (aged 16–17) from the same chemistry class in a Swedish upper secondary school. The students were either science or technology majors attending their second course in chemistry. All students were given information about the study (e.g. purpose, use of data, unrecognizability, and the right to withdraw consent) and were asked whether they wanted to participate. All students (N = 25) participated in the teaching sequence, but one student chose not to be a part of the research. The study data comprised students' argumentative texts, which were collected at the end of the intervention. The data was collected in a classroom setting, and all activities were part of the regular instruction. The texts were analysed both qualitatively and quantitatively. The research followed the ethical guidelines described by the Swedish Research Council (2017).

The students were familiar with the first author, as they knew her as a science teacher. However, the chemistry course they attended was led by another teacher, and the first author acted as an additional resource during the course. During the intervention, the first author acted as both an instructor, together with the other teacher, and a researcher. The choice of acting as an instructor during the intervention was based on the first author being prepared for the task and therefore having knowledge about argumentation and the SSI (presented below).

The SSI: Water- and fat-repellent substances in everyday products

The SSI used in this study is well suited for the chemistry subject and concerns highly fluorinated substances, more specifically, per- and polyfluoroalkyl substances (PFAS). These substances are utilized to provide water- and fat-repellent properties in a variety of products used in everyday life. For the intervention, two questions were formulated in which the students were asked to decide whether to buy products containing PFAS or not. One question concerned a functional jacket, and the other food packaging, such as micro popcorn or packaging at fast-food restaurants. The issue contains several of the aspects an SSI should contain, as suggested by Ratcliffe and Grace (2003). Organic environmental toxins have major effects in society, both for the environment and human health; nevertheless, many of these substances provide desirable properties in various products. Therefore, the chosen case contains conflicts of interest and it becomes a question of utility compared to risk. PFAS is a relevant topic which has been reported in the media during the year when the study was conducted. There is great uncertainty regarding PFAS, as researchers do not yet know the extent of the effects these substances may have.

Teaching sequence

The intervention was performed in eight steps (Figure 1) during five weeks. The time it took for each step varied, but the total time was ten 80-minute lessons. During the intervention, the students practiced argumentation and studied the issue of PFAS in everyday products.

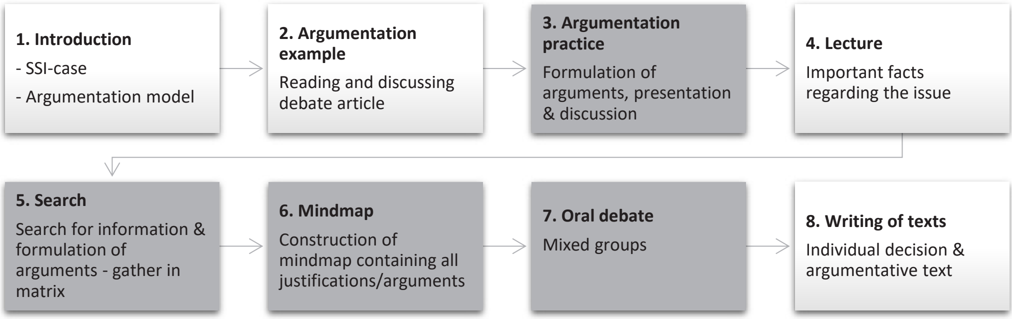


Figure 1. The different parts of the teaching sequence. Boxes in grey represent group activities.

The purpose of the first four steps was to introduce the SSI and to practice argumentation.

Step 1: The students were given a brief assignment consisting of five questions in which they were asked to choose among different alternatives and explain why they made that choice. Students' answers were then used as examples in discussions about claims and justifications. After this activity, the students were introduced to the subject area by watching a movie about environmental toxins. Finally, the argumentation framework (Christenson & Chang Rundgren, 2015) was presented, and the students were asked to read a debate article about plastics in the ocean for the upcoming lesson. They were also asked to think about what type of arguments (from the framework) the article contained.

Step 2: The debate article was discussed and the different arguments were placed into the framework. Examples were given of students' answers from the assignment in Step 1 in order to show the difference between grounded and non-grounded value justifications.

Step 3: The students were divided into groups and asked to take a stand on whether alcohol should be banned or not. They researched the effects of alcohol and discussed the issue. The goal was to formulate three arguments to support their opinion and one counterargument. The students compiled their arguments in a digital presentation, which they presented and discussed in relation to the argumentation framework with two other groups. They were also asked to discuss whether the arguments consisted of content knowledge from different perspectives.

Step 4: The students were given a lecture about important facts related to the subject area of environmental toxins. Central concepts were presented, and the students were given an introduction to the area and its complexity. The students were shown both pros and cons of chemicals used in everyday products.

Steps 1, 2, and 4 were mainly led by the first author, while the other steps were led jointly by both teachers. The next three steps (5–7) focused on preparations for the final task: the argumentative text.

Step 5: The students were presented with the two questions (described above), since the questions influenced which sources of information they would want to use. They searched for information, discussed different perspectives of the issue, and formulated arguments in groups. To get the students to actively work with the argumentation framework, the first author put together a matrix (Figure 2) in which the students gathered information and their arguments.

Claim:		
Supporting arguments		**Source** (if applicable) Trustworthy? Why?
Content knowledge	**Value**	
Counter arguments		
Content knowledge	**Value**	

Figure 2. Matrix designed from the framework by Christenson and Chang Rundgren (2015).

Step 6: The students categorized the arguments in a mind map (e.g. "environmental" and "economic").

Step 7: The students were put into new groups (2–3 students) to perform an oral debate about whether PFAS should be used or not. As support during the debate, all groups were allowed to bring their work material (i.e. the matrix with arguments and mind map). The students found out which side they were debating just a few days before the debate. Therefore, it was important for the students to prepare arguments for both sides in advance.

Step 8: The students were asked to answer a question about whether they would buy products (i.e. jacket or food packaging) containing PFAS and to write an argumentative text. When writing the final argumentative text, the students were allowed to bring the material they had worked with during the prefatory phase. They also had a list of instructions that highlighted important aspects of the argumentation framework as a support.

Data gathering

The data for this study consists of argumentative texts from 24 students, gathered at the end of the teaching sequence described above. The texts were written in digital form. As support during the writing of the texts, the students had access to the material they prepared beforehand. It took the students between 60 and 100 minutes to produce the texts, which had an average length of 800 words.

Analysis

A content analysis (Cohen, Manion, & Morrison, 2011) of the data was conducted. Initially, it was done deductively from the categories found in the argumentation framework by Christenson and Chang Rundgren (2015). The process was also inductive since other categories, as well as subcategories, emerged from the data throughout the coding process.

During the coding process, the texts were read a number of times and justifications were marked and sorted into a table. A justification was defined as a reason as to why a specific claim was made. For example, the sentence *"perfluorinated substances can cause cancer"* is seen as a justification since it can be followed by *"and therefore, I do not want to buy a jacket containing said substances"*. A sentence can also contain several justifications, as in the following one, which is considered to hold two justifications: *"high levels of the substances can <u>cause liver damage</u> and <u>reproductive problems</u>"*.

These justifications can be used as reasons for a specific claim on their own. At first, the justifications were sorted into the four categories from the framework by Christenson and Chang Rundgren (2015): *pros* and *cons* based on either *content knowledge* or *values*. These categories are called "Supporting justifications based on Content Knowledge" (SCK), "Supporting justifications based on Values" (SV), "Counter justifications based on Content Knowledge" (CCK), and "Counter justifications based on Values" (CV). The term *counter justification* connotes evidence, or a reason, employed to justify a counterargument.

Importantly, the content knowledge categories contain justifications that can be described as either content (i.e. school-subject knowledge) or context-specific knowledge (i.e. other knowledge related to the SSI). The distinction between the two is not always clear, since content and context-specific knowledge are related to each other. In this study, they are seen as concepts or facts that are related to the context of the SSI in question. Regarding the correctness of students' content knowledge justifications, only those that were correct have been included in the results. However, incorrect content knowledge justifications (N = 4) were marked during the analysis. Justifications belonging to the value categories are connected to individual values, affections, and attitudes (a definition used by Christenson et al., 2014). During the analysis, we noticed that some justifications did not fit into either the content knowledge or the value-categories. It could be that the students draw conclusions, predict future events, or make a statement that are only valid under certain conditions. For example, one student wrote, *"If the process continues during a long period of time, it will lead to high concentrations of these chemicals, and that could result in unmanageable consequences"*. This sentence offers a reason as to why the student chooses to refrain from buying products containing PFAS, hence, a justification. It is related to content knowledge, but it is not a fact, since it will only come true if certain conditions apply, and it does not show any value statements. Therefore, the categories "Supporting justifications based on Reasoning" (SR) and "Counter justifications based on Reasoning" (CR) were added.

Difficulties also arose when the justifications were to be categorized, as the boundaries between the categories were not always clear. For example, based on the definition of the SR or CR categories described above, a justification stating that increasing disease rates will have a negative effect on individual and societal economy could be categorized as either SR or CR depending on the claim. The same justification could also be seen as content knowledge, since it describes cause and effect within the social science subject. One solution would be to ascribe two codes to the same justification, but that would greatly inflate the number of justifications, distorting the results. Therefore, the category that most adequately represented the justification was chosen. In this case, it was the SCK category. There were also difficulties in drawing a sharp line between content knowledge and values in cases where the justification held value statements based on content knowledge. Many of the justifications in the value categories were based on feelings that arose from the facts surrounding the effects of the substances. The sentence *"Isn't it terrifying that the substances can travel that far and exist for so long?"* is an example of this. According to the main part of this sentence, the student thinks it is "*terrifying"*, which can be interpreted as a reason for not buying products containing PFAS. This reason is based on a feeling and is therefore a justification related to the value category SV. However, the second part of the sentence contains two justifications related to content knowledge. Since the student has already mentioned these justifications earlier in the text, they are not marked as new justifications. When knowledge and values are intertwined, and in cases where the student has not presented the fact earlier in the text, the fact-based part is placed in the content knowledge justification category and the value justification in the value justification category.

Values can be either explicitly or implicitly visible in decision-making (Kolstø, 2006). Explicit values are stated in words. In contrast, implicit values must be "read between the lines". How an individual prioritizes between different content knowledge justifications is an example of this. In this study, the focus will be on the values that are explicitly expressed by the students. How students use values to prioritize among justifications will not be analysed. Further, the value categories in the assessment framework by Christenson and Chang Rundgren (2015) make a distinction between grounded and non-grounded justifications. This distinction was made during the analysis, resulting in three justifications classified as non-grounded. The rest were considered grounded because they came with an explanation. Since there were only three non-grounded value justifications, they have not been further categorized. Nevertheless, they are presented in the results.

The justifications were sorted by the first author, who went through the data several times to ensure consistency, refinement, and exhaustiveness of coding as per the recommendation by Cohen et al. (2011). After discussions with the other authors and at research seminars, the justifications were re-sorted, by the first author, with a coherence of 97 per cent (compared to the first sorting). Approximately three per cent of the 699 justifications found were placed in another category during the last categorization. Table 1 presents the six categories.

Table 1. The six categories identified during the analysis.

Supporting arguments (pros)	**Code**	**Counter arguments (cons)**	**Code**
Supporting justifications based on content knowledge	SCK	Counter justifications based on content knowledge	CCK
Supporting justifications based on values	SV	Counter justifications based on values	CV
Supporting justifications based on reasoning	SR	Counter justification based on reasoning	CR

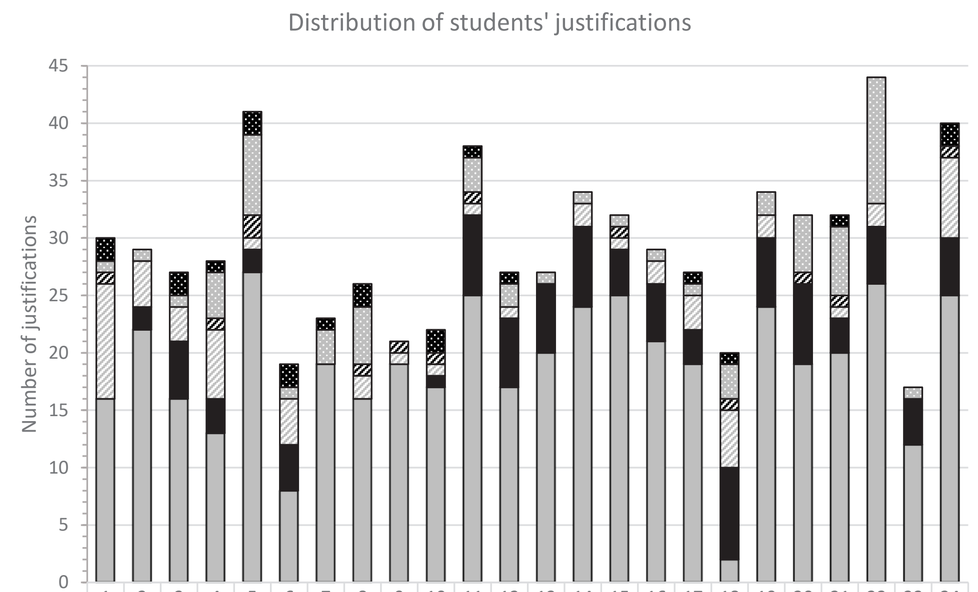
The justifications in each category were sorted into subcategories (see Table 3), which were each given a label describing the type of justification or the subject area the justification was most adequately represented by. Table 2 (below) presents an example of the data and coding.

Table 2. Examples from student texts and the definitions of the codes.

Example	Code	Subcategory	Definition
S5: *PFOS has been banned in EU countries due to its hazardous effects on health and environment. […] PFOA is suspected to be carcinogenic to humans.*	SCK	Law/policy Health effects	Students present facts, concepts or theory related to content or context-specific knowledge to support a claim
S11*: It is uncertain whether the levels of PFAS in humans are poisonous […] the level of PFAS in test animals is not equivalent to the levels in humans…*	CCK	Research field	Students present facts, concepts or theory related to content or context-specific knowledge to rebut a claim
S24: *The thought of being oblivious to the global effects of my jacket scares me.*	SV	Feelings	Students use values/affections/attitudes to support a claim
S11: *…PFAS have good properties. It would be unhygienic and unappetizing if food packaging did not repel water, dirt and fat.*	CV	Opinions/beliefs	Students use values/affections/attitudes to rebut a claim
S14: *Consumers control what is being produced. If they realize the danger with PFAS, they may force companies to change their production.*	SR	Consumption	Students draw conclusions/make conditions/make predictions of future events to support a claim
S8: *A Gore-Tex jacket lasts longer and you don´t have to buy a new one as often – this leads to less consumption, which benefits the environment and the economy.*	CR	Consumption	Students draw conclusions/make conditions/make predictions of future events to rebut a claim

RESULTS

Six categories were identified during the analysis. Four of them (SCK, SV, CCK, and CV) stem from the framework by Christenson and Chang Rundgren (2015). Since some justifications in the students' texts were conclusions based on reasoning that did not fit into either category, two more categories were added: SR and CR. Of the 24 students, all but one argued for the decision to refrain from buying products containing PFAS. The supporting justifications in each main category (i.e. Content knowledge, Values, Reasoning) are the justifications used to support the students' chosen position. Accordingly, most justifications support the argument against buying products containing PFAS, whilst some (found in text number 18, see Figure 3) support the choice to buy the products. The same applies for the counter justifications. Most of them are reasons why one should buy the product, except for text number 18, which presents reasons not to buy products with PFAS as counter justifications.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CR	2	0	2	1	2	2	1	2	0	2	1	1	0	0	0	0	1	1	0	0	1	0	0	2
SR	1	1	1	4	7	1	3	5	0	0	3	2	1	1	1	1	1	3	2	5	6	11	1	0
CV	1	0	0	1	2	0	0	1	1	1	1	0	0	0	1	0	0	1	0	1	1	0	0	1
SV	10	4	3	6	1	4	0	2	1	1	1	1	0	2	1	2	3	5	2	0	1	2	0	7
CCK	0	2	5	3	2	4	0	0	0	1	7	6	6	7	4	5	3	8	6	7	3	5	4	5
SCK	16	22	16	13	27	8	19	16	19	17	25	17	20	24	25	21	19	2	24	19	20	26	12	25

Figure 3. Distribution of justifications in each student's text.

Table 3. Distribution of justifications between the six categories and subcategories.

Main categories	*Subcategories*	*Supporting justifications*		*Counter justifications*		
Content knowledge		**Code SCK**		**Code CCK**		
	Health effects	134		4		
	Properties	94		37		
	Source/presence/circulation	89		9		
	Research field	41		18		
	Ecology/Environment	48		-		
	Alternatives	27		10		
	Economy	1		11		
	Law/policy	9		2		
	Industrial usage	6		-		
	History	3		-		
	Consumption	-		2		
	Total:	**452**	**64.7 %**	**93**	**13.3 %**	
Values		**Code SV**		**Code CV**		
	Opinions/beliefs	23		10		
	Ethics/morality	18		3		
	Feelings	10		-		
	Deliberations	8		-		
	Total:	**59**	**8.4 %**	**13**	**1.9 %**	
Reasoning		**Code SR**		**Code CR**		
	Consumption	22		3		
	Health effects	10		-		
	Research field	10		-		
	Economy	3		5		
	Function	1		5		
	Ecology/Environment	5		-		
	Alternatives	2		3		
	Risk assessment	-		4		
	Properties	3		-		
	Law/policy	2		-		
	Source/presence/circulation	1		-		
	Harm reduction	-		1		
	History	1		-		
	Experience	1		-		
	Total:	**61**	**8.7 %**	**21**	**3.0 %**	**Total:**
	Total:	**572**	**81.8 %**	**127**	**18.2 %**	**699** **100%**

Justifications based on content knowledge

The students' justifications were placed in this main category if they contained content or context-specific knowledge. Content and context-specific knowledge are concepts or facts related to the SSI in question. No distinction was made between facts related to, for example, the school subject chemistry or context-related information linked to the SSI. The category is made up of supporting (SCK) and counter justifications (CCK) from eleven different subject areas (Table 3). Examples from both sides are presented below.

Supporting justifications – SCK

All students provided supporting justifications based on content knowledge in their texts, as can be seen in Figure 3. Some students (for example, students 6 and 18) presented fewer justifications based on content knowledge, but on average, the majority of the justifications in the texts belong to this category. SCK is the most frequently used category, making up 64.7 per cent of all justifications.

Many of the justifications in the SCK-category point to negative effects of PFAS. Almost all students chose to refrain from buying PFAS products, using the negative aspects of PFAS to support their choice. Various health effects are present in most texts, and the quote below (S21) is a typical example. This quote also highlights the uncertainty surrounding the research field of PFAS, which is another example of content knowledge:

> S21: [A]*nimal studies have shown that high concentrations can cause liver damage, affect fat metabolism, the immune system and the reproductive system.* [...] *The uncertainty* [of effects on human health] *is due to the lack of knowledge of individual substances, but foremost because of the uncertainty of effects of different substances in combination.* (Code: SCK, Health effects, Research field)

While presenting justifications, the students often referred to different sources of information. For instance, S11 referred to the Swedish Environmental Protection Agency and the Swedish Chemical Agency while giving justifications related to the properties of PFAS, ecological effects, and the presence and circulation of the substances:

> S11: *The Swedish Environmental Protection Agency also writes that since these highly fluorinated substances are persistent and absorbed more quickly than they are broken down, they accumulate in the environment and in biological tissue. It is thus the top predators in the ecosystem that are most affected. PFAS have many different pathways in which they are spread, by water and air.* [...] *According to the Swedish Chemical Agency, PFAS spread easily over vast distances. High concentrations have been found in mammals in the Arctic.* (Code: SCK, Properties, Ecology/environment, Source/presence/circulation)

Students used justifications based on content knowledge to rebut counter justifications, as is shown in the quote from S3 below, in which the student responds to the counter justification regarding the lack of viable alternatives to PFAS. The justification contains an example of a company that stopped using PFAS and started using other alternatives.

> S3: *The answer to this is that there are alternatives, new methods are constantly being researched and developed. "Fjällräven" is a company that has replaced all highly fluorinated substances. Instead they use polyurethane which is a biodegradable plastic compound. There are also other alternatives, for example, silicon based compounds based on chains of silica and oxygen which occur naturally in our bodies. They are water repellent and withstand chemical and electrical impact.* (Code: SCK, Alternatives)

To summarize, three main themes can be identified in the SCK category, as outlined above. First, the students presented facts and information related to the SSI. Second, while presenting justifications, the students referred to information sources. Third, the students used content knowledge to rebut counter justifications in favour of their own claims.

Counter justifications – CCK

Regarding counter justifications, CCK, all students but four presented justifications from this category in their texts. The CCK category makes up 13.3 per cent of all justifications. The justifications used in this category contain facts and information speaking against students' claims. Other than that, this category is similar to the SCK category. As described above, students followed up on their counter justifications by rebutting them. In the quote below by S12 (who did not want to buy PFAS products), beneficial properties are presented, followed by negative aspects of the substances (not included in the quote):

> S12: *Functional jackets have many coveted properties such as water and fat repellence. In order to achieve these characteristics, the jackets are made of Gore-Tex and impregnated with PFAS.* […] *PFAS is a collective name for poly- and perfluorinated alkyl substances such as PFOA and PFOS. These substances are temperature resistant, persistent to fire, stable to electricity, and have the ability to repel water, grease, and dirt.* (Code: CCK, Properties)

The counter justifications also contain references to information sources. The quote below by S20 shows how this student used information about the research field from the Swedish Environmental Protection Agency to present a counter justification:

> S20: *Unfortunately, the Swedish Environmental Protection Agency shows, in the same article, that there is little knowledge about how PFAS really affect us at the levels we are exposed to daily, the doses used in animal experiments, which show harmful effects caused by PFAS, are much higher than the doses we are exposed to.* (Code: CCK, Research field)

Justifications based on values – SV and CV

The value categories contain the four subcategories "Ethics/morality", "Opinions/beliefs", "Feelings", and "Deliberations". This main category is different from the content knowledge category because the subcategories do not describe the subject area to which the justifications are tied. This is because value justifications stem from personal values or are expressed opinions, and they contain ethical considerations (as in the quote from S17 below) or are based on feelings. The justifications do contain topics related to subject areas similar to the ones used as subcategories in the content knowledge and reasoning categories, but the subject area is secondary to what the student is basing his/her justification on. An example can be seen in the quote from S17, in which both value- and knowledge justifications are intertwined, since the student (as part of ethical considerations) presented the fact that PFAS is thought to disturb the reproductive system. This fact is a justification coded as SCK; however, we chose not to add that to the parenthesis below. The quote from S1 shows another example in which the student expressed feelings related to the uncertainty regarding the harmful effects of the substances.

> S17: *It is not right that the animals, which do not use these substances, have to take the consequences.* […] *The substances are believed to disturb the reproductive system and by continuing our use, we are diminishing their chances of survival. We are harming innocent animals!* (Code: SV, Ethics/morality)

> S1: *Other PFC's are being used today* […] *but we do not know how they will affect us in the future. The uncertainty concerning perfluorinated substances and that they are found in our clothes are scary, and therefore I have chosen not to buy a jacket containing PFAS.* (Code: SV, Feelings)

The majority of the students presented justifications from the value categories. SV makes up 8.4 and CV 1.9 per cent of all justifications. Most students (20 out of 24) have at least one supporting value-based justification in their text. Twelve of the students included justifications based on values in their counter arguments, as in the quote by S21:

S21: [Describes different functions of Gore-Tex materials]. *These features can be important when it comes to events with importance to safety, such as fire equipment. Fire equipment requires a durable material, but this super function is not always necessary.* (Code: CV, Opinions/beliefs)

During the analysis in this study, the distinction between grounded and non-grounded value justifications was made. Of the three non-grounded justifications, two belong to SV "Opinions/beliefs" and one to CV "Opinions/beliefs". The rest are grounded because they come with an explanation for the students' value justifications (see the justifications presented above). S18 below is an example of a non-grounded justification. The student did not expound the reason why PFAS would not be something to worry about in relation to emissions of carbon dioxide:

S18: *There is much more to worry about, for example, all the carbon dioxide emissions.* (Code: SV, non-grounded, Opinions/beliefs)

Justifications based on reasoning – SR and CR

The justifications placed in this main category are often related to content knowledge justifications, but they are not explicit facts or knowledge about the circumstances related to the SSI. What these justifications have in common is that the student draws conclusions based on knowledge related to the context. However, it is the conclusion per se that the argument is based on:

S5: [After describing effects on the ecosystem] *it would require very high concentrations over a long period of time, therefore, this is not an acute danger to the environment.* (Code: CR, Risk assessment)

S8: *We know that it affects health and fertility in animals. Then it is possible that it also affects us, since we are mammals as well.* (Code: SR, Health effects)

In other justifications in this main category, students reflect and predict possible future events, as in the two examples below. The justifications are also only valid under certain conditions; for instance, if one thing applies, it entails certain effects, and these effects are what the student uses as a justification:

S11: *If I and other consumers stop buying PFAS products it could lead to less pollution, since the demand of PFAS products decreases, and the companies are forced to find alternatives.* (Code: SR, Consumption)

S22: *If the alternative PFAS substances prove to be as harmful as PFOA or PFOS we are taking a huge risk by using them.* [...describes known harmful effects of certain PFAS-compounds...] *These are dangerous health effects, and we do not know if other PFAS have the same effects.* (Code: SR, Properties)

Supporting justifications sorted into the reasoning category (SR) make up 8.7 per cent of the total number of justifications. The category is present in 21 of the students' texts, whereof the subcategories of "Consumption", "Health effects", and "Research field" are the most common (Table 3). The CR category, with counter justifications based on reasoning, is small and constitutes only 3 per cent of all justifications. However, it is present in 14 texts, which is more than half of the texts. Its most relevant subcategories are "Function" and "Risk assessment", to which most of the CR-justifications belong (Table 3).

DISCUSSION

This study aimed to investigate how upper secondary chemistry students justify their claims in an argumentative text after being explicitly taught about SSA and the context surrounding the SSI. As suggested by the findings, and as can be seen in Figure 3, the students mainly base their arguments on content knowledge. This applies to both supporting arguments and counterarguments. Many of the content justifications are tied to chemistry- and biology-related knowledge. In contrast, earlier studies (e.g. Christenson et al., 2014; Sadler & Donnelly, 2006) have shown that students mainly base their arguments on values. Teachers may therefore avoid working with SSI in fear of losing focus on the scientific content. On the other hand, this study shows that content knowledge can play a substantial part in student argumentation. Implementing the framework developed by Christenson and Chang Rundgren (2015) in the classroom resulted in students using content knowledge as the primary ground for their arguments and also to ground their value justifications. The framework acted as a support for the students during the teaching sequence, leading up to the final assignment (i.e. the argumentative text). According to the framework, students' SSA is of a high quality, with some variation between different students. For example, all students provide both supporting and counter justifications in their texts. The justifications in the argumentative texts also contain a breadth of different subject areas, indicating a capability to view the SSI from different perspectives and to understand the inherent complexity. Further, justifications based on values are present in the students' texts, but they constitute a smaller proportion.

The main difference between the value category and the other two (i.e. content knowledge and reasoning) is that the subcategories describe the justifications at different levels. The subcategories in the content knowledge and the reasoning categories are labelled by the different subject areas to which they are tied. Content and context-specific knowledge consist of facts and concepts related to different subject areas. This is also true for the justifications belonging to the reasoning category, except that the students take the reasoning one step further by predicting future events or by conditioning their arguments. Therefore, the value subcategories are described differently because they describe the kind of values the students use in their justifications instead of subject area. In this study, four different subcategories were identified in relation to the value category: "Opinions/beliefs", "Ethics/morality", "Feelings", and "Deliberations". All of these originate from an individual's personal values. Although one can have feelings, opinions, or ethical considerations about a topic tied to one of the subcategories in the content knowledge and reasoning categories, it is not the content that is of importance when placing a justification in the value category; rather, it is the feeling or opinion that is in focus. In comparison with the SEE-SEP model (Chang Rundgren & Rundgren, 2010) – which connects values to subject areas (e.g. Sociology/Culture, Environment/Ecology) but otherwise makes no distinction between different value justifications (e.g. feelings, moral/ethical considerations) – this study presents an alternative way to describe students' use of values as grounds for their arguments.

Content and context-specific knowledge

Research has shown that teachers may refrain from working with SSI due to a fear of diverting students' attention away from scientific knowledge (Ekborg et al., 2013). In this study, we have shown that content knowledge can make up a considerable part of SSA when students have been properly prepared for the argumentative task. Nevertheless, it is interesting to discuss where to draw the line between subject knowledge (e.g. the curriculum for chemistry) and context-specific knowledge. Here, both subject knowledge (e.g. properties and behaviour of PFAS molecules) and knowledge concerning the context of the SSI (e.g. knowledge of the research field or EU regulations of PFAS) have been placed in the same category. Many of the justifications found in the students' texts have to do with the context of the chosen SSI and would not be present in another SSI topic; they are context-specific (Hodson, 2013). However, a large number of justifications are tied to the chemistry or biology subjects and allow students to put their knowledge into a wider context, in this case, the SSI of PFAS in everyday products. The Swedish curriculum has a clear focus on the subjects' relation to the individual and the society, SSI, decision-making competence, and argumentation skills in science education (SNAE, 2011), which calls for context-specific knowledge.

Conclusions and implications

Previous studies have shown that students use values more often than knowledge to justify their arguments (e.g. Christenson et al., 2014; Sadler & Donnelly, 2006) and that there is a need for supporting and encouraging students to use knowledge as grounds for their arguments. Through a structured and supportive design, this intervention study has successfully managed to support students in doing so. Further, this study highlights the need for teachers to teach students about the process of argumentation, as well as the context of the SSI, in order to support students to achieve high quality argumentation. These results support the findings of Zohar and Nemet (2002), who also stress the importance of teaching both content and argumentation. As science teachers may not have sufficient knowledge about argumentation, this can be difficult without proper guidance. Consequently, teacher education needs to include the teaching of argumentation for future science teachers. The lesson design that has been presented in this paper may also serve as a support for teachers when working with SSA.

There are methodological differences between this study and previous studies focusing on SSA. For example, as discussed earlier, this study presents an alternative way to analyse and describe value justifications. This study also contributes with a new category of justifications, in addition to content knowledge and values, called "justifications based on reasoning". The justifications placed in this category are part of what makes students' SSA interesting: they represent examples where students take their knowledge one step further by speculating, formulating hypotheses, and drawing own conclusions on which they ground their arguments. Future research should investigate this category further to see whether it occurs in different SSAs and which possibilities it may have for students' argumentation.

There are also several limitations in this study. First, it is a small-scale case study with a limited number of participants. Therefore, the extent to which the findings can be generalized to other students or contexts is not known. Second, the first author acted as both teacher and researcher, which may have influenced the students, for instance, in terms of effort. Knowledge about, and relationships with, the students may have also influenced the analysis. Hence, other researchers have been involved in the categorization of students' justifications on several occasions. Third, the students have gone through a series of lessons designed to support the development of argumentation skills. Consequently, the specific teaching design is likely to have had a strong influence on the results, which is why the design has been described in detail. However, this also means that the study provides relevant knowledge about how to support the implementation of SSI-based science teaching.

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