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Carola Garrecht, Michael J. Reiss & Ute Harms

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'I wouldn't want to be the animal in use nor the patient in need' – the role of issue familiarity in students' socioscientific argumentation

Carola Garrecht [a], Michael J. Reiss [b] and Ute Harms [a]

[a]Department of Biology Education, IPN - Leibniz Institute for Science and Mathematics Education, Kiel, Germany; [b]Institute of Education - Curriculum, Pedagogy and Assessment, University College London, London, UK

ABSTRACT

Students' argumentation skills are considered a central tool to contribute to scientific controversies in the science classroom. Scientific controversies of social relevance (socioscientific issues; SSI) are subject to multiple viewpoints that are often rooted in diverse disciplines. However, the relationship between issue familiarity and students' multidisciplinary argumentation is still a matter under discussion. This study: (1) explores whether the selection of a particular issue (animal testing) enables students' engagement in multidisciplinary argumentation without additional issue familiarisation, i.e., using only their existing knowledge; and (2) clarifies the relationship between increased issue familiarity and students' multidisciplinary argumentation. One hundred and sixty three ninth and tenth graders participated in this study, of whom one hundred and six took part in a teaching unit to familiarise themselves with the issue of animal testing. The study's results demonstrate that animal testing constitutes an effective issue to engage students with the complexity of SSI without requiring more than basic familiarity prior to engagement. The results further demonstrate that increased issue familiarity can enhance the overall diversity of discipline-related arguments amongst students; however, not all disciplines were enhanced equally. The findings suggest that more instructional guidance seems to be needed to assist students in broadening their arguments.

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1. Introduction

One of the central goals in science education is to equip students with an understanding of science that then enables them to engage in science-related discussions that take place in their personal lives and in the wider society (DeBoer, 2000). This knowledgeability is usually referred to as scientific literacy (Roberts & Bybee, 2014). Since the term's first

CONTACT Carola Garrecht garrecht@leibniz-ipn.de Department of Biology Education, IPN - Leibniz Institute for Science and Mathematics Education, Olshausenstrasse 62, 24118 Kiel, Germany

occurrence in the late 1950s, there have been various attempts to define what aspects of knowledge, skills and dispositions genuinely constitute a scientifically literate individual (Holbrook & Rannikmae, 2009). However, students' abilities to engage in argumentation have been considered an essential facet of scientific literacy from the beginning and this remains the case (Cavagnetto, 2010; NGSS, 2013; NRC, 2012).

Roberts (2007) reflected upon the different meanings of scientific literacy and distinguished between two understandings: Vision I and Vision II. According to Vision I, scientific literacy emphasises processes and products within the disciplinary boundaries of science. Science education under this understanding aims at students mastering concepts and practices that are necessary for future scientists (Roberts & Bybee, 2014). In light of this vision, students' argumentation encompasses the construction and evaluation of evidence-driven arguments to address controversies within the science classroom (Erduran et al., 2004). Advocates of Vision II, in contrast, emphasise that scientifically literate individuals should be able to apply their scientific understanding for the negotiation of science-related, real-world issues. In Vision II classrooms, argumentation thus represents a practice that integrates *diverse* viewpoints of both a social and a scientific nature to contribute to controversies outside the science classroom (Kolstø, 2001).

To promote this second and applied vision of scientific literacy, several curricular movements have emerged during recent decades that emphasise the teaching and learning of science embedded in larger, societal contexts (e.g. science, technology, society and environment (STSE; Pedretti & Nazir, 2011); socioscientific issues (SSI; Sadler, 2004); socially-acute questions (SAQ; Simonneaux, 2014); for an overview see also Bencze et al., 2020). All of them, to differing degrees, aim to derive meaning from authentic *issues* in which the respective science content occurs (i.e. particular science-related topic that is debated; Zeidler et al., 2019). However, the relationship between the particular issue and students' argumentation is still a matter under discussion (Baytelman et al., 2020; Osborne et al., 2016; Topcu et al., 2010).

Prior research has indicated that some issues seem to be more accessible for students than others (Christenson et al., 2014; Osborne et al., 2016). This highlights the importance of choosing suitable issues for teaching, especially if the outcome is to develop students' argumentation. Since teachers frequently report being challenged by short instruction time and a lack of pertinent materials (e.g. Lee et al., 2006; Pedersen & Totten, 2001), a suitable issue should preferably engage students in argumentation without requiring too much prior familiarity. In contrast to this practical demand, Baytelman et al. (2020) recently suggested that familiarity about the particular issue plays an important role in constructing arguments from multiple perspectives. These perspectives are often rooted in diverse disciplines. Since SSI are inherently controversial, the ability to identify these multidisciplinary arguments seems crucial (Sadler et al., 2007). Even though Baytelman et al. (2020) were able to explore this correlation due to their study's ex-post-facto-design, meaning that all data were collected in one session without an intermediate intervention, the causal effect of increased issue familiarity on multidisciplinary arguments remains unanswered.

To better understand how issue familiarity affects students' multidisciplinary argumentation, two successive research endeavours will guide this paper. First, we will examine whether the selection of a particular issue (here: animal testing) enables students' engagement in multidisciplinary argumentation *without* additional familiarity. Secondly, this paper builds upon Baytelman et al. (2020) promising evidence by further investigating the missing link between the effects of increased issue familiarity on students' ability to form arguments rooted in different disciplines.

2. Theoretical background

Promoting students' argumentation skills is a central element of science education (e.g. NGSS, 2013; NRC, 2012) and a prominent interest in science education research (e.g. Dawson & Carson, 2018; Zohar & Nemet, 2002). Argumentation describes a dynamic process of negotiation which promotes the (re-)construction of knowledge (Ford, 2008). In contrast to the process of reasoning, which describes an internal examination (Mercier et al., 2017), argumentation is understood as process in which learners communicate these considerations (Means & Voss, 1996). The argument, in turn, is the most central tool in an argumentation. It can be understood as 'an externally manifested set of propositions 'designated' as premises and conclusion' (Walton, 2020, p. 400).

In science education, students' ability to apply these propositions has received considerable research attention (e.g. Evagorou et al., 2012; Osborne et al., 2004). The most dominant scheme for such evaluations, according to Chinn (2006), has been Toulmin's Argument Pattern (TAP; Toulmin, 1958). TAP analytically exemplifies the different components of an argument with regards to data, warrant, backing, rebuttal and claim. For the classroom, TAP has been successfully extended and modified by researchers such as Erduran et al. (2004) so as to measure the quantity and quality of students' arguments. Besides TAP, scholars, including Schwarz et al. (2003), have developed further frameworks, aiming to evaluate the structure of students' arguments – see Sampson and Clark (2008) for an overview.

However, several shortcomings of TAP and comparable structure-focused schemes have been identified in recent years. Nussbaum (2011) and Nielsen (2013), for example, note that the dynamics of an argument, due to its dialogic nature, are lost when solely focusing on the structure of individual arguments. Sampson and Clark (2008) and Jafari and Meisert (2019) maintain that concentrating on the structural complexity of an argument largely overlooks its content and accuracy. As a result, recent studies have established analysis frameworks that give more emphasis to the content of an argument. Such studies have researched various aspects of argumentation, ranging from students' use of value statements (e.g. Grace, 2009) to the role of emotions (e.g. Basel et al., 2014).

In science education, numerous content-oriented studies have focused on students' argumentation in the context of SSI (Cavagnetto, 2010). SSI describe controversial social issues that are blended with science-related concepts and/or procedures (Sadler, 2011). SSI are unlike other issues that are traditionally addressed in the science classroom because they represent open-ended problems, meaning that a clear-cut and straightforward solution remains undetermined (Kolstø, 2006). Due to their 'wicked' nature, SSI can be framed in multiple ways, depending on who is examining it (Hoffmann, 2016). The debate about these controversial problems is therefore dominated in society by diverse interest groups (Sadler et al., 2007). As a result, different proposed solutions are subject to a variety of perspectives that are often rooted in different disciplines.

Considering this authentic complexity presents an integral part of their negotiation which makes SSI 'ideal topics for argumentation' (Zeidler & Sadler, 2007, p. 201).

The SEE-SEP model of Chang Rundgren and Rundgren (2010) constitutes an analysis framework for socioscientific argumentation that reflects the complexity of SSI particularly well. In their understanding, socioscientific argumentation should not be limited to students' abilities to attend to each other's opinions, but also to employing arguments that touch upon different disciplines and stem from knowledge, value or experience. To assess students' multidisciplinary exploration of SSI within this paper, we will focus on the six disciplines that have been identified by Chang Rundgren and Rundgren (2010) as the most common disciplines in the negotiation of SSI: Sociology/culture (So), environment (En), economy (Ec), science (Sc), ethics/morality (Et), and policy (Po).

With rising interest in the potential of SSI for science education, a variety of issues have been employed to explore students' argumentation practices and skills. These range from environmental issues (Evagorou & Osborne, 2013), through genetic engineering (Zohar & Nemet, 2002), to climate change (Dawson & Carson, 2018). Although this indicates the heterogeneity of investigated issues, there remains a lot of uncertainty about their impact on students' argumentation. While some studies conclude that reasoning patterns are consistent across issues (e.g. Romine et al., 2017) other study results suggest the opposite, claiming a certain issue-dependency (e.g. Topcu et al., 2010). Besides, previous research offers only preliminary insights into students' preferences and openness to engage with different issues (Christenson et al., 2014; Osborne et al., 2016). Yet, most of the scholars in the field of science education agree that a basic familiarity with the scientific content of a SSI is needed to engage in argumentation (Grooms et al., 2018; Topcu et al., 2010; Von Aufschnaiter et al., 2008).

2.1. The role of issue familiarity in argumentation

Theoretical and empirical work in the field of (science) education shows that students require certain basic knowledge, i.e. issue familiarity, in order to engage in argumentation (Lewis & Leach, 2006; Ogan-Bekiroglu & Eskin, 2012). However, previous studies have reported differing findings as to whether more than basic knowledge improves the quality of student argumentation (for a review, see Sadler & Donnelly, 2006). On balance, the literature suggests that content knowledge does play a role in enhancing argumentation about SSI; however, the relationship might be non-linear, meaning that a certain depth of knowledge is required before knowledge shows a positive effect on argumentation. Other studies have investigated the relationship between students' knowledge and the number of their arguments, hypothesising that students with more robust knowledge will produce more arguments (Means & Voss, 1996; Schmidt et al., 2017). Evagorou and Osborne (2013), for example, examined the number of claims in students' collaborative argumentation. They found that some groups proposed more claims than others, and this indicated students' ability to present more solutions for the issue in question. A study by Sampson and Clark (2011) revealed similar results while exploring students' collaborative argumentation about a chemistry-related issue. Their analysis showed that 'higher performing groups voiced twice as many unique content-related ideas […] as the less productive groups' (p. 76). This larger number of ideas was suggested as requisite for an in-depth engagement with the issue, meaning that student had richer opportunities to exchange, modify and challenge ideas. Summarising these cases suggests that an increased number of arguments seem to indicate a more detailed elaboration of the underlying issue. This conclusion aligns with a study by Lewis and Leach (2006), who found that students who were more familiar with the particular issue were also able to identify its key elements which, in turn, enabled them to engage in an in-depth discussion.

In our paper, the number of arguments is understood as an indicator of *issue familiarity,* with a greater number of arguments, other things being equal, indicating greater issue familiarity. Issue familiarity, in turn, is understood as the knowledge about an issue, with greater familiarity enabling students to engage with the issue under debate to a greater extent (see also Han et al., 2009).

2.2. Socioscientific argumentation about animal testing

As part of this study, we propose animal testing as a powerful issue to engage students in multidisciplinary argumentation. First of all, discussing whether or not animal testing is justified requires considerations that refer to different disciplines, such as scientific (e.g. gains in knowledge), ethical (e.g. right to life), economic (e.g. cost–benefit analysis), social (e.g. medical development) and environmental (e.g. toxicology) related arguments. In addition, in contrast to many other socioscientific issues, such as climate change and nuclear power, a deep understanding of which require students' understanding of physical, chemical, and biological concepts, the scientific links connected to animal testing are limited to the broader discipline of biology. This cognitive reduction might increase the topic's accessibility to a greater number of students. Secondly, this issue may be particularly meaningful to students because of its emotional salience and its topicality, for instance its role in the development of a COVID-19 vaccine. The recent publication of undercover footage from animal testing laboratories in Germany (Hamburg), the Netherlands (Rijswijk), and the USA (New Mexico) has further stirred up public debate about the conditions and practices found on these videos. For such reasons, students might not only have a basic familiarity with the issue but also be interested to engage in discussion about it.

3. Research aims

Most of the studies in science education on students' arguments have focused on their logical structure (e.g. using tools such as Toulmin's TAP, 1958). However, as mentioned, the ethical and factual complexity of SSI might become lost when relying solely on such structure-focused schemes. This gap has been addressed by Baytelman et al. (2020) who investigated the relationship between university students' content knowledge, epistemic beliefs and socioscientific argumentation. Instead of merely inquiring about the structural components of students' arguments, these authors were also interested in their content-related diversity (namely: arguments of a social, ethical, economic, scientific and ecological nature). They concluded that a familiarity with the topic seems crucial 'not only for the quantity and quality of arguments but also for the diversity of different types of arguments that students construct, in their effort to take into consideration multiple sides and perspectives of a socioscientific topic' (p.22). Yet, the question of whether increased issue familiarity affects the diversity of discipline-related arguments that are employed remains unanswered.

The main objective of our study was to address this gap by gaining a fuller understanding of the relationship between issue familiarity and students' multidisciplinary argumentation about a current SSI. First, we investigate whether animal testing presents an effective issue that engages students in multidisciplinary argumentation *without* additional issue familiarity, i.e. using only their basic, existing knowledge. This first research step thus aims to add to what is known about the suitability of different issues at enabling students to engage in multidisciplinary argumentation in science classrooms. Secondly, we examine the effect of issue familiarity on students' multidisciplinary argumentation by conducting an intervention study that builds on the latest body of work (Baytelman et al., 2020).

4. Materials and methods

4.1. Study context and design

This study was located in a German context. As in a number of other countries, perceptions that students had performed below national expectations in the Programme for International Student Assessment (PISA) at the beginning of the century reinforced national, discourse-based reforms which aimed to promote an understanding of scientific literacy according to Vision II (see KMK, 2005). In the context of this study, it could thus be assumed that for both teachers and students argumentation represents an accepted practice within the science classroom. In order to explore the relationship between issue familiarity and students' multidisciplinary argumentation, we conducted a quasi-experimental intervention study in a pre–post-test design with a comparison group (see Figure 1). Since the intervention aimed to increase students' issue familiarity, our first step was to develop a teaching unit that gives students the opportunity to familiarise

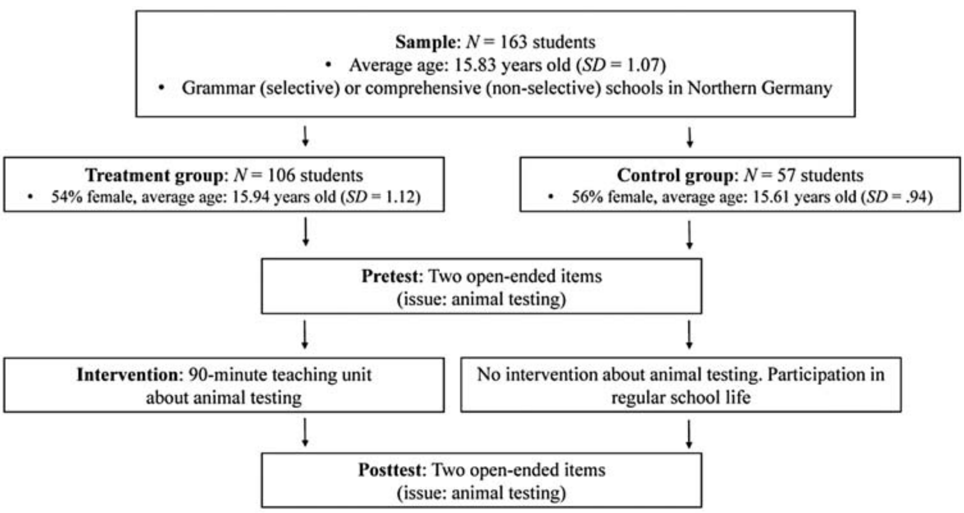

Figure 1. Overview of the study design.

themselves with the issue and the multiple discipline-related arguments that are interwoven into the issue (here: animal testing, see 4.2). Next, we developed two open-ended items, intended to engage students in socioscientific argumentation about animal testing (see 4.3). Students' written arguments were analysed using the SEE-SEP model of Chang Rundgren and Rundgren (2010, see 4.5).

4.2. The development and structure of the teaching unit

To increase students' familiarity with the issue of animal testing, we developed a 90-minutes teaching unit for upper secondary school students. The structure and content of this unit were built upon a previously developed catalogue of criteria. This catalogue distinguishes 16 independent criteria (e.g. objectivity, changing perspectives, positioning) that can be used by teachers and researchers alike to assess the quality of animal testing-related teaching materials. Each criterion was checked for suitability and subject to refinement through expert rating. All experts ($n = 44$) were either from the field of science education or conducting animal testing themselves.

The design of this teaching unit features essential characteristics of SSI-based instruction (Presley et al., 2013; Sadler et al., 2016). This involved, amongst other things, students' confrontation with a compelling real-world issue (here: animal testing), students' engagement in scientific higher-order practices (here: reasoning, argumentation, and decision-making), and a culminating activity to connect and situate students' learning (here: group discussion). In addition to these design elements, the need for open-mindedness and mutual respect for a beneficial learning environment was communicated at the beginning of the unit. To address the inherent complexity of this issue, arguments that refer to the different discipline of the SEE-SEP model were elaborated by the students as part of the 90-minute teaching unit (i.e. worksheet and role play). Table 1 presents the different activities of the three interconnected parts of the intervention.

The main activity of the intervention's first part encompassed a role play between students. According to Howes and Cruz (2009), role play is an acknowledged method to introduce and explore the different sides of a dilemma in science education. In our teaching unit, participants took the roles of two adolescents having opposing views on animal testing. The acting of a fictional conversation between the two enabled participants to experience two different viewpoints and to explore their arguments. Agell et al. (2014) demonstrated that role play is a successful way of introducing students to the complexity of animal testing. Once the dilemma had been introduced, participants individually elaborated further arguments for and against animal testing in the second part of the teaching unit. These arguments covered multiple perspectives and aimed to address the inherent complexity of this issue. Central to the third part of the teaching unit was students' participation in the classroom discussion. After students had had additional time to ponder their own personal stance on this matter, the dynamic exchange of ideas during the discussion aimed to support them in justifying and reflecting on their views.

The teaching unit strictly followed the schedule of activities presented in Table 1 to ensure comparability between classes. To further reduce the variability between classes, the first author, who has teaching experience in extracurricular and higher education, taught all lessons. In addition, teaching protocols were written by a teaching

Table 1. Structure and content of the teaching unit.

Part	Overarching task	Learning activity
	Overall learning aim: Each student will (1) recognise animal testing as an ethical dilemma, (2) acknowledge and develop arguments from diverse disciplines, and (3) explore their own views on this issue.	
Preparation	Reading background information. Exemplary sources: German Reference Centre for Ethics in the Life Sciences (DRZE); Tierversuche verstehen; German Research Foundation (DFG); Centre of Excellence for Animals in Law, Ethics and Society (TIR)	Reading the background information was assigned as homework after the pre-test and at least seven days before the actual intervention to ensure that all students have a basic familiarity with the issue at the beginning of the teaching unit. The fact-based homework informed students about possible procedures of animal testing, implications and the legal situation.
Part 1	Exploring the dilemmas behind animal testing	'Pictures on a wall' (flashlight activity: recognition of intuitive thoughts and feelings towards animal testing). 'Chain of information' (sorting slips of paper: refresh background information from homework). 'Role play' (recognise two different perspectives on animal testing).
Part 2	Exploring different perspectives on animal testing (for or against, and everything in-between)	'What are the options?' (addressing the diverse courses of action). 'Worksheet: diverse arguments' (exploring diverse arguments for and against animal testing, working out the underlying values).
Part 3	Exploring one's personal stance in this matter and taking part in a structured discussion	'What is more important?' (sorting and weighting arguments with respect to one's own views). 'Where to put your sticker' (anonymously mapping one's personal opinion towards animal testing on a poster). 'Group/Classroom discussion' (partaking in group/classroom debate).

assistant in an attempt to control for any discrepancies in the delivery of the teaching unit.

4.3. Item development and data collection

Two open-ended items, along the lines of Christenson et al. (2014) and specific to the issue of animal testing, were designed to investigate students' multidisciplinary argumentation (see Table 2). Both items were part of a broader questionnaire which contained four items in total. The first item, which aimed to assess students' moral awareness, contextualised the issue of animal testing within a specific dilemma (i.e. medical developments vs using laboratory animals). For this paper, only the two open-ended items that assessed students' argumentation (see Table 2) are considered. Prior to data collection, the questionnaire was piloted in three subsequent rounds with $n = 119$ participants

Table 2. The two context-specific items used to investigate students' socioscientific argumentation.

Item number	Item task
Item 1	'Imagine there is to be a poll about the banning of animal testing in Germany. Would you be for or against the banning of animal testing? Choose one side and state at least three arguments for your chosen view.'
Item 2	'There are people who have different views to you about whether animal testing is acceptable. What sorts of people might these be and what arguments might they use to back up their opinions?'

(1st round: $n = 37$ university students with a major in education, philosophy or biology from Schleswig-Holstein and Baden-Württemberg, $M = 23.6$ years, $SD = 3.08$ years; 2nd round: $n = 76$ German citizens, $M = 32.7$ years, $SD = 11.5$ years; 3rd round: $n = 6$ pupils, $M = 14.8$ years, $SD = 0.69$ years). Each round of piloting focused on the items' language (e.g. neutral wording), content (e.g. age-appropriateness) and structure (e.g. clarity).

As our study involved human participants, ethical approval was obtained from the Ministry for Education (state level) prior to data collection. Participation in the study was voluntary and parents had to sign an informed consent form for their children to participate. Data were collected in 2018, between May and July. The questionnaire which included both items (see Table 2) was filled in by students using netbooks that were provided by the authors of this study. In light of this emotional topic, we decided to focus on written assessment because it allowed students to commit, after at least some initial reflection, to their own view, reducing potential social pressure that might have been experienced in oral argumentation during the intervention (Kutnick & Roger, 1994). In addition, to examine the effect of issue familiarity on students' multidisciplinary argumentation, we required comparable post-test responses from both the treatment group and the comparison group. Students spent approximately 20 min in total on both tasks.

4.4. Sample

The sample ($n = 163$ students; $M = 15.83$ years; $SD = 1.07$ years) were aged between 15 and 18 years and attended either grammar (selective) or comprehensive (non-selective) schools in Northern Germany. The treatment group consisted of $n = 106$ students (54% female, mean age = 15.94 years; $SD = 1.12$ years) and participated in the teaching unit (see 4.2.). These students were asked to answer both items (see Table 2) before and after the intervention. The second group of students, who functioned as a comparison group, consisted of $n = 57$ students (56% female, mean age = 15.61 years; $SD = .94$ years) and answered the same two items at the same measurement points as the treatment group. In contrast to the treatment group, the comparison group did not participate in the teaching unit, having instead regular teaching according to the national standards (KMK, 2005). None of the participating classes, neither the treatment group nor the comparison group, had been explicitly taught about animal testing before or during the testing period. To monitor whether the students of the comparison group familiarised themselves with the topic during the pre- and post-test, they were asked in the post-test whether they had used other sources (articles, videos, and webpages) to learn about the issue. Only five students answered this question in the affirmative.

4.5. Data analysis

To draw conclusions about students' *issue familiarity*, we counted the number of arguments produced by students before and after the intervention; an increased number of arguments was operationalised as increased issue familiarity. To investigate students' *multidisciplinary* argumentation, the SEE-SEP model served as an analysis scheme (So, En, Ec, Sc, Et, and Po; Chang Rundgren & Rundgren, 2010). Building upon this analysis scheme, a coding manual for the issue of animal testing was developed by the first author.

This manual included coding rules as well as anchor examples for each discipline. In a second step, the manual was discussed and revised with one of the assistant researchers who helped during the delivery of the teaching unit. All of the arguments generated in this study were analysed individually using the final manual. Exemplary arguments and their coding can be found in Table 3. A more in-depth description of the SEE-SEP analysis scheme, as well as more examples of coding, can be found in Chang Rundgren and Rundgren (2010).

After coding, the interrater reliability was calculated to assure the reliability of the results. A second rater, another assistant researcher who helped with collecting the data, received a brief introduction on how to use the coding manual before coding about 25% of the material. The interrater reliability was found to be good (Cohen's $k = .79$). Arguments that were scored differently by the two raters were re-examined until a common agreement was found.

To investigate students' use of discipline-related arguments, the analysis followed a two-step procedure focusing on: (1) the number of different disciplines that the students used in their arguments, i.e. their *diversity*; and (2) the number of arguments the students used *within each discipline*, i.e. their *depth*.

The data analysis first investigated the *total number* of arguments employed by students pre- and post-test. It then investigated whether the *diversity* of disciplines increased in students' arguments over time. For this purpose, whenever a reference was made to one of the six disciplines within a student's argument, that discipline was coded as 'given' (numerical coding: 1). Disciplines that were not referred to in a student's argument were coded as 'not given' (numerical coding: 0). This analysis step was repeated for each argument in students' responses. With regard to the *diversity* of disciplines, it did not matter whether or not a discipline that was referred to was touched upon more than once since the focus was on the mere presence or absence of each discipline. The total score was obtained for each student to determine the number of different disciplines to which they referred. From all the arguments that were generated by students in the pre-test, only one student failed to present at least one valid (i.e. codable) argument. This was not the case in the post-test, where all students stated at least one valid argument. In total, from all arguments collected in the pre- and post-test, only a handful of arguments within students' responses could not be coded to one of the six disciplines. These arguments either lacked validity or were irrelevant to the intentions of our categorisation. Finally, the data analysis investigated whether the *depth* of use of any of the disciplines increased in students' arguments over time. Since this study aims to examine the effect of issue familiarity on students' multidisciplinary argumentation, depth does not refer to the profoundness of students' reasoning (i.e. different components of an argument with regards to data, warrant, backing, rebuttal and claim),

Table 3. Exemplary arguments and their coding.

Exemplary quote by students of this study	Coding
'Actually, animals such as mice have a similar gene expression to humans. So they can be used as a model for human diseases'	Science-related
'I think that it would be good [to ban animal testing] because animals are forced to do it.'	Ethics-related
'I think developers might tolerate animal testing because they make money with it'	Economy-related

but the number of arguments that stem from the same discipline. For example, a student might use two science-related and one ethics-related argument in the pre-test compared to three science-related and one ethics-related argument in the post-test. Such a student shows the same diversity of disciplines pre- and post-test but the total number of arguments stemming from science (i.e. the depth) has increased.

5. Results

5.1. Number of arguments as an indicator for students' issue familiarity

In total, 1318 arguments were generated by participating students (pre-test: 610; post-test: 708). A repeated measures ANOVA showed that the mean number of arguments differed significantly between the two measurement times ($F(1, 161) = 6.34$, $p = .013$, $\eta_p^2 = .038$). A statistically significant interaction between time and groups indicated that the use of arguments depends on the group affiliation ($F(1, 161) = 19.61$, $p < .001$, $\eta_p^2 = .11$) (Figure 2). Additionally, the main effect for the treatment group was statistically significant ($F(1, 161) = 11.55$, $p = .001$, $\eta_p^2 = .067$). The means and standard deviations pre- and post-test for both groups are presented in Table 4.

5.2. Students' multidisciplinary arguments

To investigate students' use of discipline-related arguments, the analysis followed a two-step procedure focusing on (1) the *diversity* of disciplines used and (2) their *depth* within students' argumentation.

Using paired t-tests, the data revealed a statistically significant difference in the diversity of disciplines used before and after issue familiarisation within the treatment group ($t(105) = 3.62$, $p < .001$, $d_{z\,=}$ .35). There was also a statistically significant difference in the diversity of disciplines used between the comparison and the treatment group post-test ($t(161) = 2.531$, $p = .012$, $d = .42$).

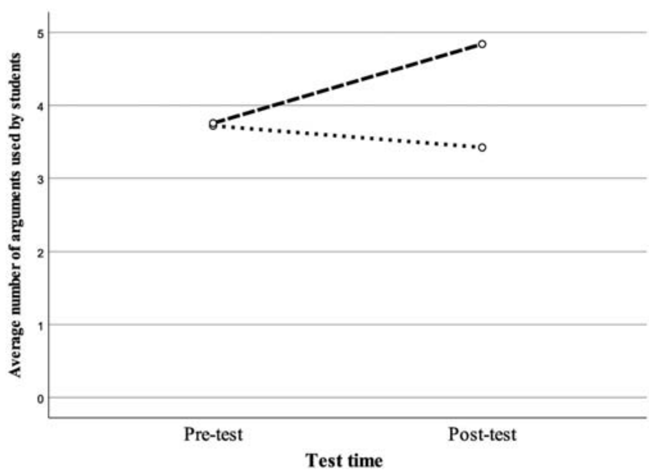

Figure 2. Average number of students' arguments pre- and post-test (long dashes: treatment group; short dashes: comparison group).

Table 4. The means and standard deviations of relevant variables pre- and post-test for both groups.

	Treatment group		Control group	
	Pre-test *M (SD)*	Post-test *M (SD)*	Pre-test *M (SD)*	Post-test *M (SD)*
Total number of arguments	3.75 (1.41)	4.84 (1.97)	3.72 (1.49)	3.42 (1.31)
Sociology/culture-related	0.35 (0.60)	0.32 (0.54)	0.37 (0.56)	0.37 (0.59)
Economy-related	0.23 (0.44)	0.45 (0.68)	0.25 (0.47)	0.23 (0.46)
Environment-related	0 (0)	0 (0)	0 (0)	0.02 (0.13)
Science-related	1.03 (0.81)	1.61 (1.16)	0.91 (0.74)	0.77 (0.66)
Ethics/morality-related	2.09 (1.14)	2.29 (1.12)	2.11 (1.11)	1.96 (0.96)
Politics-related	0.07 (0.25)	0.19 (0.42)	0.07 (0.26)	0.11 (0.31)

Table 5. Results of univariate testing (multidisciplinary arguments).

Disciplines	df	Mean square	*F*	Sig.	Partial Eta-square
Society	1	.03	.067	.795	.000
Economy	1	2.206	4.356	.038	.026
Environment	1	.011	1.87	.173	.011
Science	1	19.497	14.764	.000	.084
Ethics	1	4.246	2.498	.116	.015
Politic	1	.284	1.96	.163	.012

To provide a clearer picture concerning students' use of discipline-related arguments in terms of *depth* (i.e. number of arguments that use a specific discipline), the data were further analysed after counting the total number of discipline-related arguments within students' arguments. First, a multivariate test (MANOVA) was conducted to examine associations between the different variates (So, Ec, En, Sc, Et, Po). For the calculation, the change in the number of discipline-related arguments from before to after the intervention was used. Across all variates, there was a statically significant difference in the use of discipline-dependent arguments ($F(6, 156) = 4.59$, $p < .001$, $\eta_p^2 = .15$).

Next, univariate testing indicated that partaking in the teaching unit results in a statistically significant effect on the use of science-related ($F(1, 161) = 14.76$, $p < .001$, $\eta_p^2 = .084$) and economy-related ($F(1, 161) = 4.36$, $p = .038$, $\eta_p^2 = .026$) arguments (see Table 5). For the other variates, the effects failed to reach statistical significance. The mean and standard deviation pre- and post-test and for both groups are presented in Table 5.

Simple effects analyses were then conducted (Figure 3). For science-related arguments, the test showed that there was significant development *within* the treatment group from pre- to post-test ($F(1, 161) = 27.46$, $p < .001$, $\eta_p^2 = .146$). This was not the case for the comparison group ($F < 1$). In the post-test there was a significant difference *between* both groups ($F(1,161) = 25.57$, $p < .001$, $\eta_p^2 = .137$) which was not found in the pre-test ($F < 1$). For economy-related arguments, the test showed that there was significant development *within* the treatment group from pre- to post-test ($F(1, 161) = 10.73$, $p = .001$, $\eta_p^2 = .062$) but not in the comparison group ($F < 1$). In addition, there was a significant difference in the post-test *between* both groups ($F(1, 161) = 5$, $p = .027$, $\eta_p^2 = .03$) which was not the case in the pre-test ($F < 1$).

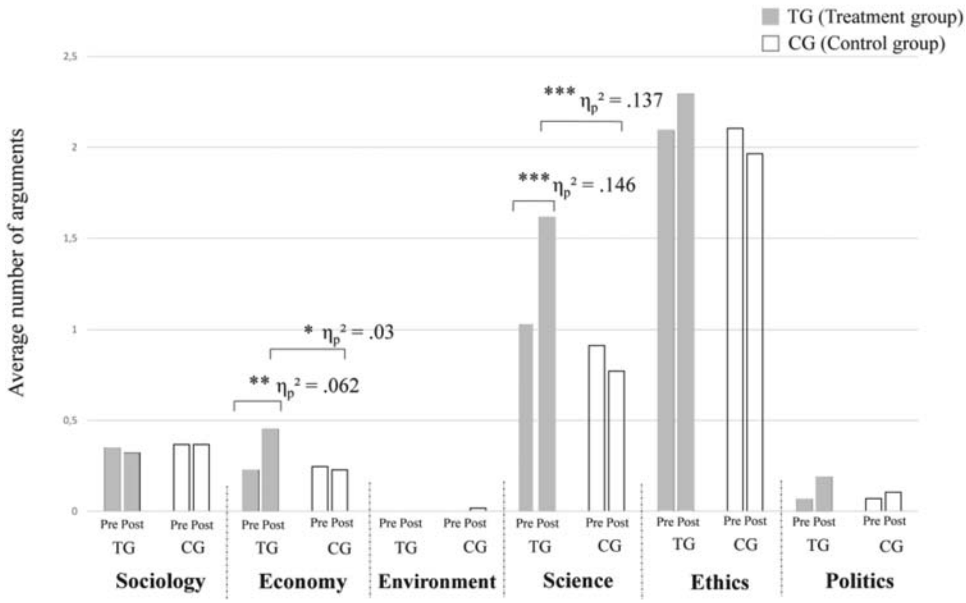

Figure 3. Use of multidisciplinary arguments compared between treatment and comparison group in pre- and post-test.

6. Discussion

Vision II scientific literacy encompasses a student's capacity to identify science-related social issues and to evaluate and express their own view in a multi-perspectival manner (Holbrook & Rannikmae, 2009). These perspectives are often rooted in diverse disciplines that need to be inquired and communicated. In exposing students to SSI, it is presumed that students recognise the complexity that derives from the particular issue, helping them to translate this diversity of reasons into their subsequent arguments (Sadler et al., 2016). The main objective of this study was to extend the current literature by gaining a better understanding about the relationship between students' multidisciplinary arguments about a current SSI and issue familiarity. First, we examined whether animal testing presents an effective issue that engages students in multidisciplinary argumentation *without* additional familiarity. Secondly, we assessed the effect of increased issue familiarity on students' multidisciplinary arguments. Similar to Baytelman et al. (2020), we analysed students' arguments in terms of disciplines that are related to social, environmental, economic, scientific, ethical and political aspects.

6.1. Animal testing as an effective issue for argumentation

Even though the body of work on the significance of particular issues for argumentation is rather limited, previous studies have suggested that some issues might be easier for students to engage with than others (Christenson et al., 2014; Osborne et al., 2016). At the same time, a range of studies has documented teachers' challenges regarding SSI instruction, including formal obstacles such as limited instruction time and a lack of pertinent materials (e.g. Lee et al., 2006; Pedersen & Totten, 2001). A suitable issue should therefore, if possible, engage students in argumentation without requiring too much prior issue familiarity. As part of this study, we proposed animal testing as potentially a particularly effective issue to engage students in multidisciplinary argumentation even *without* additional knowledge. To evaluate this hypothesis, students' arguments from the pre-test were central to the analysis.

The analysis of our data indicates that students were able to create arguments that referred to a reasonable number of different disciplines *before* participating in the teaching unit, covering most of the analysed disciplines in the pre-test. This implies that animal testing constitutes a suitable issue to engage students with the complexity of an SSI without requiring more than their basic, existing knowledge. In this case, the basic familiarity with the topic is likely to be due in part to its presence in the media (see 2.1.), supporting the broad consensus within the science education community that a basic familiarity with an issue is necessary for students to engage in argumentation about it (e.g. Grooms et al., 2018; Topcu et al., 2010; Von Aufschnaiter et al., 2008). Furthermore, this result reflects students' genuine interest in engaging in a discussion about this particular issue (see also Agell et al., 2015).

6.2. Relationship between issue familiarity and multidisciplinary argumentation

6.2.1. The number of arguments as an indicator for increased issue familiarity

In order to draw conclusions about the relationship between issue familiarity and students' multidisciplinary argumentation, it was first necessary to document a difference in students' issue familiarity subsequent to the teaching unit. The results of our study show that the treatment group employed significantly more arguments after the intervention in comparison to the pre-test and the comparison group, indicating increased issue familiarity. Similar to the interpretation of other scholars, we interpret the increase in arguments as indicating a more elaborate consideration of the issue (see also Evagorou & Osborne, 2013; Means & Voss, 1996; Schmidt et al., 2017). The present data are also consistent with findings by Lewis and Leach (2006) who implemented learning activities about a bioethical issue (gene technology) to explore students' socioscientific argumentation. One of their findings indicated that students were able to engage in a more thorough discussion once they were more familiar with the issue and thus were able to identify the issue's key aspects.

6.2.2. The relationship between issue familiarity and multidisciplinary argumentation

For a more complete understanding regarding the role of issue familiarity on students' proposed arguments, the development of students' arguments from the pre- to post-test was examined in a two-step procedure: First, data analysis was limited to the mere occurrence of a discipline within students' argumentation to see if the *diversity* of disciplines (i.e. number of disciplines each student used) increased across time. Secondly, the number of students' arguments within each discipline was investigated in order to determine the *depth* of their occurrence. The results indicate that, overall, increased issue familiarity enhances the diversity of discipline-related arguments amongst students; however, not all disciplines were enhanced equally in depth. It seems rather that some of the disciplines that have already been frequently used by students in the pre-test were also predominant in the post-test, while other disciplines tend to be underrepresented both pre- and post-test. This novel insight can be considered from two positions.

On the one hand, the increase in depth of selected disciplines potentially indicates that students were able to draw upon more discipline-related concepts subsequent to the teaching unit, which possibly enabled them to strengthen their previous arguments (see also Haro et al., 2020; Von Aufschnaiter et al., 2008). Following this line of reasoning, one important factor might have been students' participation in the group/classroom discussion. Even though group discussions can have severe limitations, e.g. students ganging up on each other or taking extreme or under-explained positions in the debate (Kutnick & Roger, 1994), they offer opportunities. First, possible cognitive conflicts that arose during the debate might have forced students to adjust their conceptual understanding and, eventually, lead to increases in their learning in a certain topic area (Jafari & Meisert, 2019; Nussbaum & Sinatra, 2003). Secondly, students' dynamic exchange of ideas can enable them to practise justifying and defending their claims, check their arguments for efficacy and internal strength, and address contradictory points (Jafari & Meisert, 2019; Mercier et al., 2017; Sadler, 2004). These opportunities could have helped students to validate and strengthen their previous arguments with further discipline-related evidence.

On the other hand, the deepening of previously manifested disciplines has to be viewed critically. One of the main reasons why educators advocate the implementation of SSI is students' authentic experience with controversial issues. This is also reflected in didactic suggestions, as noted in Kahn and Zeidler (2017), highlighting that students' introduction to different perspectives of an issue is a central part of the teaching approach. Considering an SSI from multiple perspectives which often touch upon diverse disciplines is held to improve the quality of learners' decision-making (Chang Rundgren & Rundgren, 2010; Lindahl et al., 2019; Wu & Tsai, 2007) and further reflects students' depth of reasoning (Nussbaum & Schraw, 2007). Based on these theoretical and empirical propositions, we offered students several opportunities during our 90-minute teaching unit to explore the different perspectives (including arguments grounding in diverse disciplines) that pervade animal testing. Yet, our results indicate that students strengthened their previously manifested arguments instead of considering a more balanced variety of disciplines.

One possible explanation for students' lack of a more balanced consideration of discipline-related arguments can be derived from a psychological stance, suggesting that students, especially when unused to engaging in reasoned argument, keep to their previous views in order to avoid cognitive overload (Kuhn & Udell, 2003). The tendency to stick with previous argumentation patterns has also been shown in several other studies reporting students' general difficulty in changing perspectives within an argument (e.g. Evagorou et al., 2012; Kuhn, 2018). In the study by Evagorou et al. (2012), for example, students' written arguments on a local animal-related SSI (red vs. grey squirrels) were investigated. One of their main findings was that students primarily used evidence that supported their previously manifested position while ignoring contradictory information. This observation suggests that students applied something like a 'selective focus' on what information should be included within their socioscientific argumentation. Likewise, Zeidler et al. (2002) explored students' understanding of the nature of science using animal testing as an issue that captures the ethical considerations of scientific practices particularly well. As part of their study, students were confronted with anomalous data and information, so that students needed to deal with counterevidence to their previously indicated view on animal testing. Similar to the study by Evagorou et al. (2012), the researchers found evidence that some students just ignored or rejected the presented data while others 'hold the data in abeyance, i.e., the data was believed, but was not a factor used in the students' subsequent reasoning about the problem' (p.360). This 'selective focus' might have also been evident in our study, with students using evidence from only the disciplines on which they usually draw. When, for example, some students perceive science-related arguments rather than ethical arguments as strengthening their position, they might end up predominantly drawing on science-related arguments, simply because it fits their viewpoint.

Previous research suggests that students tend to keep the arguments they made initially (e.g. Chang & Chiu, 2008; Driver et al., 2000); our results not only support this conclusion but show that this seems also to be true for the disciplines that students use in their argumentation. Given this, merely increasing issue familiarity while presenting different arguments and perspectives may not be enough to encourage a more balanced consideration of discipline-related arguments by students. More instructional guidance, for example tools such as illustrated charts and maps of possible perspectives (e.g. Ke et al., 2020), might support students to broaden their arguments.

7. Limitations, implications, and further research

One of the main limitations of this study is that we did not explicitly measure students' content knowledge, i.e. by using a formal measure, to determine their issue familiarity. Instead, we decided to use the quantitative development of proposed arguments as evidence for a greater familiarity due to participation in the teaching unit. This approach was mainly chosen due to the limited testing time. Additionally, we assumed that administering content knowledge tests from particular disciplines (e.g. science knowledge) would not adequately capture the multifaceted nature of this issue (knowledge needed from diverse disciplines, e.g. science, ethics, economics). However, as Baytelman et al. (2020) argue, assessing students' familiarity using concept maps can be a resourceful method to evaluate the internal organisation of students' understanding. Further, it can be assumed that individual factors, such as participants' motivation to learn about animal testing, had an influence on the degree to which they spent their cognitive resources familiarising themselves with the issue under debate (see Zeidler, 2014). Collecting this additional information using qualitative methods such as concepts maps would have resulted in a more robust conclusion and is thus recommended in further studies.

Another limitation of this study concerns the assessment of students' multidisciplinary arguments. While we deliberately chose to focus on written assessment (i.e. which arguments students *decided* to write down), we acknowledge that the interactive discourse during the intervention may have played an important role in the development and selection of these arguments. Neglecting the richness of the classroom interaction means that we have only limited insight into which of the post-test arguments might be the result of the previous classroom discussion. Such negotiation processes, where diverse arguments might have been jointly classified as relevant or irrelevant, might have had an impact on both the selection and the number of arguments generated by the treatment group within the post-test. On the other hand, participating in the intervention allowed additional opportunities for the treatment group to contextualise the issue of animal testing. Again, this interactive engagement could have impacted students' motivation and response behaviour in the post-test.

We are aware that developing a teaching unit is a highly selective endeavour. In a study by Evagorou and Osborne (2013), for example, different students perceived the same issue differently, which highlights that even carefully designed teaching instructions do not work the same for each individual. It thus seems essential to keep in mind that our results might have differed, depending on the structure of the teaching unit. We tried to reduce this variability by using our previously developed catalogue of criteria during the design process. However, we have only limited insight as to whether all disciplines were discussed by students to equal extents during our intervention. Equally, we expect that the teaching unit did not only increase students' issue familiarity but potentially affected also other outcomes, such as students' ethical awareness. While this was not examined as part of this study, it would be worthwhile examining such possibilities in future research.

Lastly, while our study revealed evidence that not all disciplines were enhanced equally in depth due to increased issue familiarity, we need to emphasise that we operationalised depth as the number of arguments stemming from the same discipline. Choosing this method of analysis is thus accompanied by the constraint that we cannot make any conclusions with regard to the profoundness of students' reasoning (e.g. different components of an argument with regards to data, warrant, backing, rebuttal and claim).

An implication of the present study concerns the inclusion of SSI within the classroom setting. As previous studies in the field of science education and the results of this paper suggest, negotiating complex societal issues entails the inclusion of multidisciplinary perspectives. This highlights the interdisciplinary dynamics of the classroom, emphasising the potential of progressive teaching pedagogies such as co-teaching (Forbes & Billet, 2012). Animal testing can serve as a valuable issue to connect science (specifically, biology) and social science (e.g. economics and politics) teachers to enable holistic learning experiences. As argued in Christenson et al. (2014), 'explicitly making students (regardless of their discipline background) connect interdisciplinary resources to their SSI learning in school will likely enhance the students' skills to develop good-quality argumentation when discussing SSI' (p. 596). The SEE-SEP model can serve as a framework for teaching design purposes in this respect.

An aspect that was not explicitly examined as part of this study concerns the role of emotions. While other studies, such as Herman et al. (2021), demonstrate how place-based (i.e. immersive) SSI experiences can encourage students to tap into their emotions, future research needs to investigate to what extent this is equally possible in a classroom setting. The study presented here could provide a good basis for such an endeavour, since the issue of animal testing and the structure of the intervention already offer starting points for an emotional discourse. With regard to the particular research interest of this study, we suggest further examinations that inquire to what degree emotions guide the choice of discipline-related arguments.

Another important question remains to be addressed. Within this study, animal testing has been argued to be a particularly effective issue with relatively little knowledge needed beforehand. The question therefore arises as to whether this effect, due to increased issue familiarity, would have been similar for other SSI issues (e.g. climate change). Further research should examine the effect of issue familiarity on students' multidisciplinary argumentation across varying issues including issues that are cognitively more demanding. Only such studies could clarify to what degree our results are transferrable. Researching a variety of issues might also allow a classification by difficulty, which could offer teachers an opportunity to choose more or less challenging SSI according to students' capabilities.

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ORCID

Carola Garrecht http://orcid.org/0000-0003-4363-6968
Michael J. Reiss http://orcid.org/0000-0003-1207-4229
Ute Harms http://orcid.org/0000-0001-6284-9219

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