education sciences

Article

Reasoning on Controversial Science Issues in Science Education and Science Communication

Anna Beniermann *, **Laurens Mecklenburg** and **Annette Upmeier zu Belzen**

Biology Education, Humboldt-Universität zu Berlin, 10099 Berlin, Germany; laurens.mecklenburg@web.de (L.M.); annette.upmeier@biologie.hu-berlin.de (A.U.z.B.)
* Correspondence: anna.beniermann@hu-berlin.de

Abstract: The ability to make evidence-based decisions, and hence to reason on questions concerning scientific and societal aspects, is a crucial goal in science education and science communication. However, science denial poses a constant challenge for society and education. *Controversial science issues* (CSI) encompass scientific knowledge rejected by the public as well as *socioscientific issues*, i.e., societal issues grounded in science that are frequently applied to science education. Generating evidence-based justifications for claims is central in scientific and informal reasoning. This study aims to describe attitudes and their justifications within the argumentations of a random online sample (N = 398) when reasoning informally on selected CSI. Following a deductive-inductive approach and qualitative content analysis of written open-ended answers, we identified five types of justifications based on a fine-grained category system. The results suggest a topic-specificity of justifications referring to specific scientific data, while justifications appealing to authorities tend to be common across topics. Subjective, and therefore normative, justifications were slightly related to conspiracy ideation and a general rejection of the scientific consensus. The category system could be applied to other CSI topics to help clarify the relation between scientific and informal reasoning in science education and communication.

Keywords: argumentation; reasoning; justifications; socioscientific issues; societally denied science; controversial science issues; science communication; science education

check for updates

Citation: Beniermann, A.; Mecklenburg, L.; Upmeier zu Belzen, A. Reasoning on Controversial Science Issues in Science Education and Science Communication. *Educ. Sci.* **2021**, *11*, 522. https://doi.org/10.3390/educsci11090522

Academic Editors: Moritz Krell, Andreas Vorholzer and Andreas Nehring

Received: 8 August 2021
Accepted: 3 September 2021
Published: 8 September 2021

1. Introduction

The OECD Learning Compass 2030 [1] highlights the rapid changes confronting our society and, consequently, the importance of adaptive education in formal and informal learning environments. It emphasizes the need to think and act responsibly "towards collective well-being" [1] based on knowledge, attitudes, values, and skills (including reasoning and critical thinking) as a 21st-century goal [1]. In contrast to this goal, science denial poses a constant or even growing challenge for society [2] and science education [3]. Informed citizens should be able to make evidence-based decisions on questions concerning scientific and societal aspects, e.g., health and environmental issues [4].

The inevitable connections between science and society in science education are bundled under the term *socioscientific issues* (SSI), defined as "societal issues with conceptual or technological ties to science" [5]. SSI are scientific topics that are often discussed controversially by the public [6]. They are well-acknowledged as contexts for science learning [7,8], as the SSI approach integrates scientific, sociological, and ethical content to foster reasoning on complex questions [9]. For example, the current COVID-19 pandemic illustrates the rise in controversy between society and science and, moreover, in doubt about scientific findings [10].

While the scientific foundation of some SSI is mostly accepted by the public (e.g., knowledge about stem cells), controversy may arise with the ethical dilemmas of its application (e.g., stem cell research for medical purposes) [11]. Other SSI are based on societally controversial science that may even be rejected by parts of the public (e.g., anthropogenic causes of climate change), while being quite undisputed among scientists [11]. These topics are referred to as *societally denied science* [11] or *controversial science issues* (CSI) [12]. Attitudes toward CSI, i.e., their rejection or acceptance, highly rely on individual norms and values that do not necessarily result from scientific reasoning [13].

As science and technology develop rapidly, opportunities to encounter a variety of SSI, on which decisions must be made, and CSI, on which attitudes must be formed, become more frequent. Fostering the ability to make informed decisions on such complex issues and problems using evaluation and reasoning is not only a crucial aspect of general scientific literacy [14,15] but also a central goal of science education [16,17] and science communication [18,19]. Scientific reasoning [20,21] and informal reasoning (i.e., everyday reasoning on ill-structured problems) [22] on SSI and CSI entail the evaluation and justification of claims.

Several researchers have pointed out that argumentation is a core competence for reasoning and scientific inquiry [23], as well as central to science education in general [24]. There are few studies on argumentation in science communication [25], but it is a potentially beneficial field to bridge science communication and science education [18]. Argumentation in terms of SSI and CSI involves an ethical dimension, so socioscientific argumentation is a distinct process from scientific argumentation [26]. Multiple studies have demonstrated that reasoning on SSI [27,28] improves the complexity and quality of students' arguments concerning both scientific and socioscientific issues and can improve students' argumentation skills [29] and critical scientific literacy [30].

Different approaches to assessing argumentation have been used in science education [31]. *Toulmin's Argument Pattern* (TAP) [32] in particular has been applied in various ways [33]. However, TAP is predominantly used to assess the quality of students' arguments [34] and focuses on an argument's structure [35]. To date, few studies have examined the content of arguments [27,35] or justifications [36].

Furthermore, most research on informal reasoning and argumentation in the context of SSI and CSI focuses on either school [27–29,33,35] or university students [16,36,37], but similar analytical approaches to argumentations used by the public [18] could provide insights into controversial debates on scientific issues in everyday life. This research aims to describe different kinds of justifications used when people reason informally on selected CSI based on their attitude, using a fine-grained category system.

2. Theoretical Background

2.1. Socioscientific Issues (SSI) and Controversial Science Issues (CSI)

"Controversial Science Issues are scientific topics that, by their very nature, create discussions, debates, and questions because students are intrigued by these issues, question them or even have significant doubts about them" [12] (p. 26). Often, the description of controversy in the relationship between science and society is left implicit in science communication [38,39] as well as science education [36]. Borgerding and Dagistan [11] differentiate between three categories of CSI: *active science*, *societally denied* and *societally accepted science*, and SSI (Figure 1).

Controversies within active science are located within the scientific community itself (actual scientific frontier debates) [11]. Societally denied science refers to a negative attitude (i.e., rejection) toward scientific knowledge among the public (i.e., "x is not true"). This scientific knowledge was nevertheless generated within the scientific community and a scientific consensus on it exists [11].

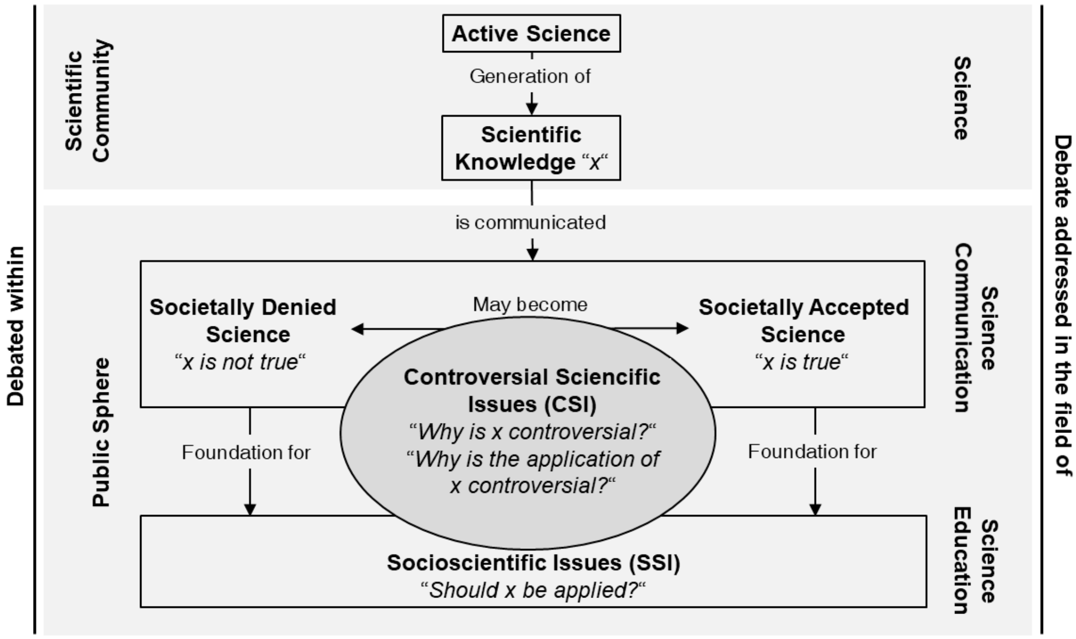

Figure 1. Relationship between controversial science issues, active science, societally denied and accepted science, and socioscientific issues (adapted from [11]).

Both societally denied science and societally accepted science can serve as a foundation for SSI [11]. For instance, knowledge about stem cell research counts as societally accepted science [11], even if the application of this research can be addressed as controversial when teaching SSI. SSI are highly relevant to society and are often discussed controversially in the context of science education [5]. Examples of SSI include stem cell research, environmental issues and their possible solutions, and the creation of genetically modified organisms [40], and therefore, the applications of scientific knowledge in these areas [11]. Normative questions, like "Is the application of this technology just?" are addressed in typical SSI, reflecting the fact that SSI cannot be resolved by science and scientific inquiry practices alone [11]. SSI have an ethical dimension concerning the relationship between science, technology, and society [41] as well as a complex societal dimension [5]. Problems in the context of SSI are open-ended, ill-structured, subject to multiple perspectives, and they lack clear solutions [37].

However, not all controversial scientific topics addressed in educational contexts fit this definition of SSI. Issues may be controversial and contested within the public sphere without being ill-structured and/or without lacking clear solutions. SSI are often described as inherently controversial [9,35] or as one kind of controversial issue [27,42]. Following the ideas that SSI are one kind of CSI and that a publicly contested issue is not necessarily denied by the public, we describe CSI as an umbrella term (see Figure 1), comprising different approaches of science communication and science education. When engaging in CSI, the question is not whether a certain issue is true or just but what the reasons for its controversy are.

Examples of CSI are evolution [43] and climate change [44], since parts of society doubt their theoretical scientific foundation, i.e., have a negative attitude toward them. Attitudes are conceptualized here as an affective assessment of an attitude object (e.g., evolution, climate change) [45]. Nevertheless, these topics do not lack a clear solution and are not ill-structured. For other CSI, such as vaccination [46] and GMOs [47], the controversy refers, at least in part, to the application of technology and touches the field of SSI.

Moreover, different factors influence attitudes toward CSI topics, hence the distinction between societally denied and societally accepted science. Most influencing factors that affect the rejection of scientific knowledge or applications are affective, such as emotions, ideology, or worldview, and are referred to as the roots of attitudes [13]. Attitudes toward vaccination depend on risk perception, barriers, trust, calculation, and responsibility for society [46], while factors like religious belief [43], trust in science, and knowledge about the *nature of science* (NOS) influence attitudes toward evolution [48]. Climate change attitudes are influenced by political identity [49] and an individualistic worldview [50], and attitudes toward GMOs are affected by views about natural purity [51] as well as emotions and intuitions [52]. These different factors illustrate the issue-dependency and high heterogeneity of predictors of the controversiality of a topic [53,54]. However, some factors seem to be general predictors of the acceptance and rejection of scientific knowledge, like conspiracy ideation [55] and knowledge about NOS [56].

2.2. Informal and Scientific Reasoning

Engagement in SSI often involves argumentation and decision-making processes that require reasoning processes, i.e., processes of building and evaluating arguments [57]. For a long time, research on reasoning focused on formal reasoning about well-defined problems [58] and followed a "deduction paradigm" [59]. However, it has been demonstrated that human reasoning is prone to biases, and everyday reasoning is in most cases informal reasoning [58]. Both formal (scientific) and informal reasoning are processes of generating and assessing arguments [60]. While the problems addressed in scientific reasoning are often well-defined and the respective premises are explicit, problems in informal reasoning are ill-structured and the premises are not always stated [61]. Informal reasoning tasks often involve generating and evaluating positions on complex issues that lack clear solutions [5]. However, the coordination of theory and evidence [4,60], as well as generating evidence-based justifications [60], is central in informal and scientific reasoning: "Foundational abilities that lie at the heart of both types of reasoning are the ability to recognize the possible falsehood of a theory, and the identification of evidence capable of disconfirm" [60] (p. 74). These abilities align with the epistemic dimension of scientific reasoning as described by Osborne [21].

As SSI typically involve contentious and open-ended problems, their negotiation and resolution can be characterized by informal reasoning [5,61], which is especially suitable for processes like decision-making about actions for which supporting and opposing arguments exist [57]. The ability to informally reason on SSI has been described as a crucial component of scientific literacy [5] and a central goal of science education [62].

In addition to components of scientific reasoning [20,21], reasoning on SSI requires the integration of societal and ethical aspects, also referred to as moral reasoning [63,64]. Sadler, Barab, and Scott [8] proposed the construct of *socioscientific reasoning* (SSR) to assess the reasoning practices associated with SSI. While research on SSR highlights the integration of ethical components that require moral reasoning [42], reasoning on CSI is not necessarily a matter of moral reasoning but a matter of personal attitudes and knowledge. This is because the questions concerning CSI are neither open-ended nor unsolvable dilemmas [11]. Therefore, frameworks developed to assess SSR competencies [65], decision-making on SSI [66], and SSI attitudes [67] cannot be applied to CSI in which a clear scientific consensus concerning scientific knowledge and/or its application has been reached. Assessing how people reason concerning their attitude toward a CSI asks for different approaches, e.g., the identification of informal reasoning types [37,61,68]. While some research results suggest that reasoning is consistent across different topics [65,69], other studies describe a topic-specificity [70,71].

2.3. Argumentation Frameworks

Argumentation is the communicative part of reasoning [22] and is addressed more and more by science curricula around the world [33]. Argumentation in science is an essential skill, not only for scientists and science students but also for citizens, to enable them to make informed decisions on (socio-)scientific issues in everyday life [33].

Argumentation in general can be described as an interplay of constructing claims or explanations and the corresponding evidence [32,72] to justify something [73]. A fine-grained conceptualization of argumentation has been an ongoing challenge for researchers, and a variety of frameworks exist [31]. Aside from differences among these frameworks focusing either on content [28], structure [74], or the epistemological quality [75] of arguments, all of these frameworks rely on Toulmin's Argument Pattern (TAP) [32]. The TAP builds a general structure of arguments (Figure 2) and a foundation to assess them [33].

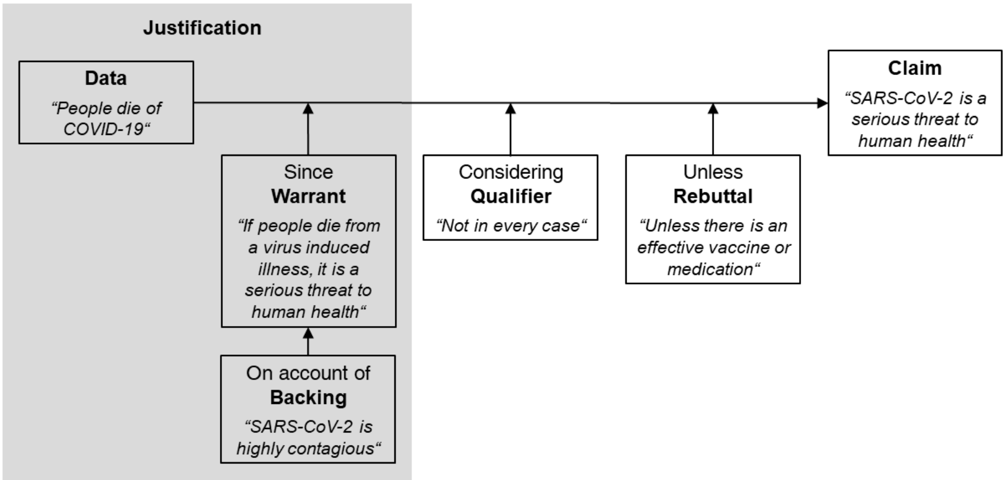

Figure 2. Toulmin's Argumentation Pattern (adapted from [32,33]) and its application to a complex argument concerning the CSI of SARS-CoV-2.

The *claim* of an argument is its conclusion. It is a statement of commitment [33] that every individual can agree or disagree with. The claim is based on several elements of the argument, with *data* representing the evidence for the claim being the central element. The data needs a *warrant* as a conclusive rule, turning the data into a relevant reason to support the claim. The warrant itself can furthermore be based on additional information called a *backing*. Because those three compartments form the justifying part of a persuasive argument [32] they are subsequently subsumed as the *justification* of a claim. The justification is opposed to the *rebuttal*, which contradicts it, and the *qualifier*, which describes the extent to which the justification allows valid conclusions.

As humans are easily capable of connecting statements in a logical way, the warrant is sometimes left implicit [76]. In the given example, the fact that people die from COVID-19 (i.e., data) can lead to the conclusion of SARS-CoV-2 posing a serious threat to human health without formulating the warrant (i.e., that the possible death forms a serious threat to human health). Equally, the data can be left implicit. Taking this into account, the articulation of a justification does not always include both data and warrant but sometimes appears as only one of the two components.

The TAP is often used as an analytical framework to evaluate argument quality [33]. When assessing arguments, an adapted version of TAP is often used. Qualifiers are often neglected to reduce the complexity [77–79]. The claim-evidence-reasoning approach is an established adaptation of the framework, in which, in addition to claim and evidence (i.e., data), warrant and backing are summarized as reasoning [79].

However, using TAP or its adapted forms as an analytical tool has also been criticized [33] due to the ambiguity of the arguments' elements [80] and the context-dependency of their interpretation [81]. In particular, differentiating between data and warrant, as well as warrant and backing, is difficult and depends on the context [77,82]. These challenges, as well as approaches that merge data and warrant [82], underpin the justification component (see Figure 2).

Several other studies that assessed arguments did not rely on TAP but analyzed arguments dichotomously by focusing on one claim supported by a ground, i.e., a reason [28,36]. Often, *subjective* and *objective* justifications are distinguished [36,83]. A comparable distinction was provided by Jafari and Meisert [27], who distinguished between normative and fact-based reasoning. Objective justifications are sometimes further divided into *evidential* and *deferential* justifications [83], with deferential justifications appealing to an authority [83]. Justifications were found to be heterogeneous within a person's argumentation and to differ among different CSI [36].

Additionally, several studies have indicated the relation between knowledge about NOS and argumentation skills [84,85]. Studies on argumentations in the field of SSI predominantly focus on argument quality based on the TAP or adapted forms. However, when it comes to the argument's contents and the types of justifications within arguments, few studies are available [27,86].

2.4. Research Questions

Several researchers have pointed out that instruction and conceptual knowledge of argumentation can foster the use of more complex [28] and more fact-based [27] arguments in the science classroom. There are still societal debates on scientific topics that are not disputed in the scientific sphere and do not lack clear solutions, and these topics count as CSI. Scientific knowledge, or its application that is partly rejected by the public, points to negative attitudes toward a topic. As roots of such attitudes are known to be mostly affective [13], this leads to the question of how people justify these attitudes.

An assessment of justifications within arguments on CSI in the public sphere is a necessary first step to identify overall tendencies and context-dependencies in justifications as one element of informal reasoning. In the long run, a resulting framework may help equip students with the necessary skills to participate in these public debates.

Our study addresses the following research questions:

1. To what extent can justifications identified in the field of CSI be grouped, with regard to theoretical criteria? (RQ1)
2. To what extent are justifications specific for certain CSI (topic-specific)? (RQ2)
3. How are acceptance and rejection of CSI related to the use of different justifications? (RQ3)
4. How does knowledge about NOS, religiousness, and conspiracy ideation relate with the use of different justifications? (RQ4)

3. Materials and Methods

3.1. Participants and Data Collection

We conducted an online survey in German, distributed via social networks to reach the public in an informal learning context. Postings included a short introduction to the topic and targeted communities interested in CSI, e.g., through a comment on videos on genetically modified food (GMF; YouTube), anti-vaccine groups (Facebook), and science communicators (Twitter). This random sampling was justified by the aim to reach out to a heterogeneous sample and collect a wide range of different justifications on different CSI. Data were collected within a two-month period in summer 2020.

In total N = 398 volunteers took part in the survey, of which N = 265 completed the questionnaire up to the last page. Participation in the survey was voluntary and during free time, which might explain the high dropout rate. It was possible to skip questions or leave the survey at any point. All open answers were analyzed, regardless of if the data set was complete. For closed questions, listwise deletion was applied. The age of participants ranged from 16 to 85 with an average of 41 years. Participants from all 16 German provinces took part, and the education level ranged from high school students and people who left school without a degree to post-doctoral researchers.

3.2. Instruments

The research design was adapted from Lobato and Zimmerman [36]. Their survey included four CSI topics (evolution, climate change, GMF, vaccination) and involved confronting participants with a statement (i.e., claim) reflecting the scientific consensus on each topic (Table 1). We added a fifth statement on SARS-CoV-2 to the survey, as the pandemic has led to the most substantive large-scale, open, and public discussion of epidemiology and science in recent history [87]. The statements used by Lobato and Zimmerman [36] were modified whenever they seemed to express epistemological considerations that could also serve as justifications, like "Evolution is the best explanation" or "Medical research has demonstrated" (Table 1).

Table 1. Statements reflecting scientific consensus on five CSI topics (modified based on [36]). Statements reflect the claim in TAP [32].

CSI Topic	Original Statement [36]	Adjusted Statement	Adjusted Statement (German)
Evolution	Biological evolution is the best explanation for explaining the varieties of species of life.	The variety of life forms and species is rooted in evolution.	Die Vielfalt an Lebensformen und Arten ist auf Evolution zurückzuführen.
Climate Change	The earth is experiencing a period of global climate change that human activity is contributing to.	The earth is experiencing a period of global climate change that human activity is largely contributing to.	Die Erde unterliegt einem klimatischen Wandel, zu dem der Mensch maßgeblich beiträgt.
Genetically modified foods (GMF)	Genetically modified foods [also known as GM or GMO foods] are largely safe for human consumption.	Genetically modified foods are largely safe for human consumption.	Genetisch veränderte Lebensmittel sind größtenteils sicher für den menschlichen Verzehr.
Vaccination	Medical research has demonstrated that childhood vaccinations are largely safe and effective.	Vaccinations are largely safe and effective.	Impfungen sind größtenteils sicher und effektiv.
SARS-CoV-2	-	The coronavirus (SARS-CoV-2) is a serious threat to human health.	Das Corona-Virus (SARS-CoV-2) ist eine ernsthafte Bedrohung für die menschliche Gesundheit.

Participants' attitudes toward the CSI topics (i.e., acceptance or rejection of the scientific consensus) were measured using a five-point scale to rate their agreement with the five claims. The participants were subsequently asked to justify (i.e., data/warrant/backing) their attitude on each claim in an open answer format and to think of possible reasons to change their position (i.e., rebuttals). In the following analysis, we focus on the justifications.

In addition, other potentially influencing variables were assessed: knowledge about NOS [88], religiousness [43,89], and conspiracy ideation [90]. The NOS measure focused on the tentativeness of scientific knowledge ("development" scale) with items like "New findings might change what scientists hold as true" [88]. The original seven items were reduced to six items. The scale measuring religiousness consisted of five items such as "I believe in God" [43,89]. The scale on conspiracy ideation [90] included items like "I think many important things happen in the world, which the public is never informed about" [90]. All of these scales measured agreement on a five-point rating scale.

3.3. Data Analysis

Results of all rating scales were merged to sum scores per scale. The rating items to assess attitudes toward claims concerning the five CSI topics were merged to one sum score for further analyses, representing attitudes toward scientific consensus.

Open answer format responses (i.e., arguments) were analyzed using qualitative content analysis [91] and the software MAXQDA Plus (VERBI Software, 2019, Berlin, Germany). Components of the analysis are semantic units; every semantic unit was coded once.

As a first step, based on TAP, we deductively derived an operationalization to identify the semantic units within respondents' arguments that can be categorized as justifications (Figure 3). This step was necessary since, even if the open answer format question concretely asked about justifications, some answers contained other argumentative elements or unrelated components.

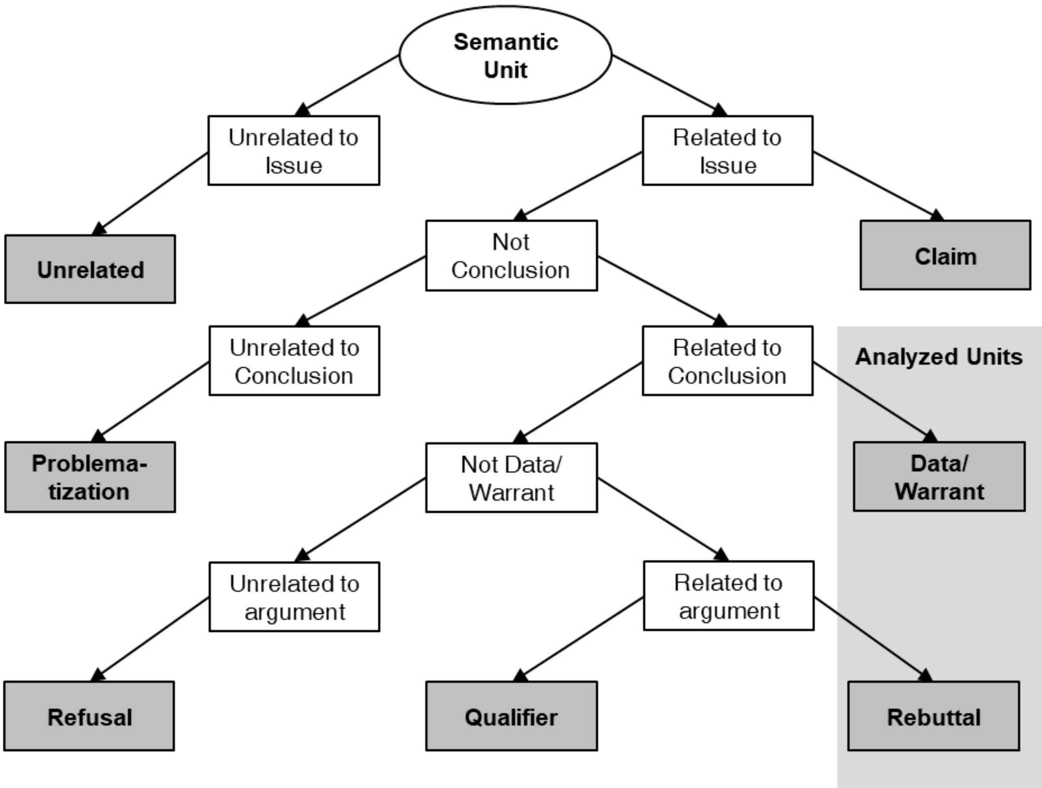

Figure 3. Operationalizing Toulmin's Argumentation Pattern [32] to isolate the justification (i.e., analyzed unit) of the argument proposed in the open answer format as the first step of the analysis.

If the semantic unit named reasons supporting the participant's position concerning the claim (e.g., "The risk of dying from the disease is higher than dying from the vaccine") it was coded as *warrant/data,* since those two argument components, as postulated by Toulmin [32], rarely appear explicitly as two distinct units. In this case, the warrant (i.e., "If the risk of dying from the disease is higher than dying from the vaccine, the vaccine is safe and effective") is left implicit, as is often the case in informal logic [76]. The conceptualization of Toulmin [32] also includes *qualifiers* influencing the magnitude of an argument (e.g., "If the vaccine is developed and tested responsibly") and *rebuttals* contradicting the conclusion (e.g., "Some people die from the side effects of vaccines"). For the following analysis of the justifications, the rebuttals were merged with warrant/data as justifications (i.e., analytic unit; Figure 3), because the statement "Some people die from the side effects of vaccines" either justifies or rebuts a participant's position.

If the semantic unit was completely unrelated to the claim, it was coded as *unrelated*. If it was a restatement of the claim captured in the rating scale (e.g., "I think vaccines help") it was coded as *claim*. If the semantic unit was unrelated to the initial statement, e.g., the safety and effectiveness of vaccines, but still related to the issue (e.g., "No one should be forced to be vaccinated") the unit was coded as *problematization*. Semantic units that referred to the initial statement without using any argumentative component (e.g., "Why would I answer that?") were coded as *refusals*.

The first deductive coding step resulted in a majority of answers justifying the statement, as intended in the open question (Table 2). There was no evidence of structural differences between stated argument components for or against scientific consensus. The stated argument components did not depend on the attitude measured.

Table 2. Frequencies (proportions) of argument components among the five CSI topics following the first deductive coding step. The grey row displays the proportion of semantic units identified as justifications.

Argument Component	Evolution	Climate Change	GMF	Vaccination	SARS-CoV-2	Total
claim	5 (1.3%)	13 (3.6%)	12 (3.1%)	13 (3.2%)	3 (0.8%)	46 (2.4%)
data/warrant/rebutt (i.e., justification)	350 (88.8%)	289 (80.1%)	300 (76.5%)	325 (79.9%)	333 (84.1%)	1597 (81.9%)
qualifier	17 (4.3%)	23 (6.4%)	22 (5.6%)	34 (8.4%)	37 (9.3%)	133 (6.8%)
problematization	2 (0.5%)	23 (6.4%)	41 (10.5%)	25 (6.1%)	10 (2.5%)	101 (5.2%)
refusal	6 (1.5%)	2 (0.6%)	6 (1.5%)	4 (1.0 %)	5 (1.3%)	23 (1.2%)
unrelated	14 (3.6%)	11 (3.1%)	11 (2.8%)	6 (1.5%)	8 (2.0%)	50 (2.6%)
Total	394 (100%)	361 (100%)	392 (100%)	407 (100%)	396 (100%)	1950 (100%)

The semantic units identified as justifications underwent a second qualitative content analysis to build up the deductive-inductive category system and answer the research questions. Therefore, we started by gathering similar content in fine-grained subcategories and subsequently generalized the categories more and more [91] based on those presented by Lobato and Zimmerman [36]. In this way, it was possible to categorize the justifications based on content and build types of justifications on CSI topics. To improve the objectivity of our category system, a different researcher conducted a second coding on 30 complete data sets (11.3% of complete data sets) [92]. These double coded data sets are a representational sample to encompass the spectrum of the material. Cohen's kappa indicates a substantial intercoder agreement ($\kappa = 0.68$) [92]. Based on a discursive analysis of the coding results, codings were discursively changed when coding errors were identified. This led to increasement of Cohen´s kappa ($\kappa = 0.84$) and a refinement of coding descriptions.

The amount and proportion of coded semantic units per type of justification were calculated and compared across the five topics. To analyze relations between types of justifications and other variables, correlations were calculated.

4. Results

The claims reflecting the scientific consensus on the five CSI topics were generally accepted, representing a positive attitude toward these topics. The most accepted claim was evolution (95.3 % agreement), followed by climate change (87.6%), vaccinations (86.0%), SARS-CoV-2 (82.6%), and finally GMF (57.5%), the most contested claim (Table 3).

Figure 4 displays the deductively-inductively built fine-grained category system to distinguish different types of justifications on CSI. The categorization resulted in five types of justifications, with 25 subcategories. A justification that cannot be falsified or is dependent on individual beliefs belongs to the *subjective* type, and every other justification is *intersubjective*. Subjective justifications refer to normative statements that are grounded in values and beliefs (e.g., *ideology:* "God created all living beings"; *naturalistic fallacy:* "This is not safe, because it is not natural"; *argumentum ad hominem:* "Virologists are not trustworthy"). Intersubjective justifications were further distinguished into those referring to specific data to support the claim (*evidential*) or referring to a third entity as an authority (*deferential*). The mere mention of "evidence" did not count as an evidential justification but was categorized as a reference to a body of knowledge and therefore as deferential. The determining differentiation between evidential and deferential justifications was their specificity; while deferential justifications refer to a rather general body or lack of knowledge about the topic, evidential justifications are quite focused on the single CSI.

Table 3. Frequency (proportion) of acceptance of scientific consensus concerning each CSI topic.

CSI Topic	Rejection	Undecided	Acceptance	Total
Evolution	13 (3.4 %)	5 (1.3 %)	361 (95.3 %)	379 (100 %)
Climate Change	17 (5.3 %)	23 (7.1 %)	282 (87.6 %)	322 (100 %)
GMF	61 (21.3 %)	61 (21.3 %)	165 (57.5 %)	287 (100 %)
Vaccination	26 (9.4 %)	13 (4.7 %)	239 (86.0 %)	278 (100 %)
SARS-CoV-2	29 (10.7 %)	18 (6.7 %)	223 (82.6 %)	270 (100 %)

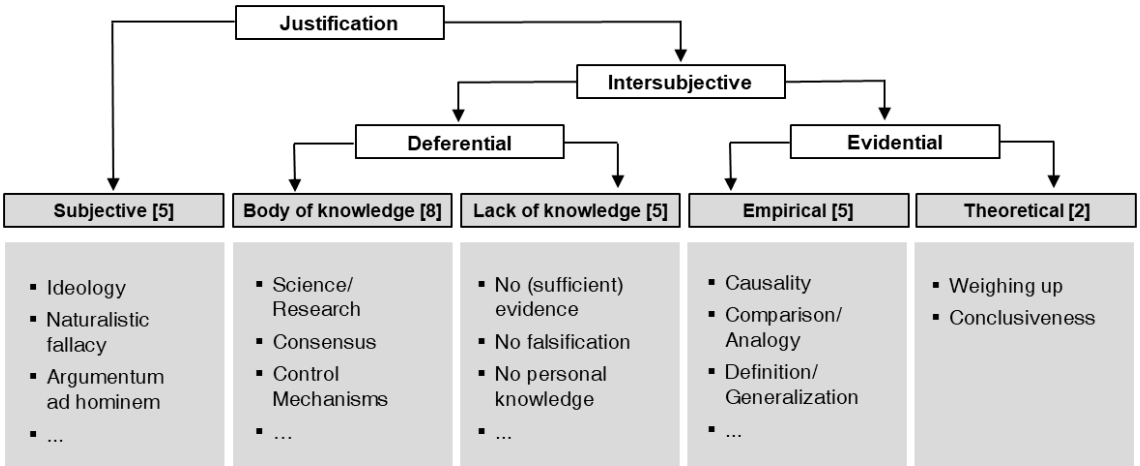

Figure 4. Category system of justification types concerning attitudes toward claims on CSI topics. Number of subcategories per category is in square brackets.

Deferential justifications were further divided into justifications referring to *a body of knowledge* (e.g., *science/research:* "That was proven by science"; *consensus:* "Almost all scientist agree on it"; *control mechanisms:* "There is a strict and transparent approval procedure for vaccinations") or a *lack of knowledge* (e.g., *no (sufficient) evidence:* "We don't know enough about it"; *no falsification:* "To date, there is no evidence against it"; *no personal knowledge:* "I don't know enough about this"). The evidential justifications were categorized as either *empirical* or *theoretical* justifications. While empirical justifications referred to verifiable real-world phenomena (e.g., *causality*: "As shown by the eradication of smallpox"; *comparison/analogy:* "SARS-CoV-2 is not more dangerous than the flu"; *definition/generalization:* "This is the case, since we have a global pandemic"), the theoretical justifications drew conclusions, weighed up, or referred to conclusiveness (e.g., *weighing up:* "The risk of dying from the sickness is higher than dying from the vaccine"; *conclusiveness*: "This is a conclusive explanation").

All identified justification types were identified across all five topics. However, some justification types were more common depending on the particular CSI topic addressed. While subjective, empirical, and theoretical justifications tended to be rather topic-specific, deferential justifications appeared with a similar frequency across most of the topics (Table 4). Therefore, references to a body or lack of knowledge were used quite similarly across the different CSI. However, on the safety of GMF, the most contested statement, a comparably high number of justifications refer to a lack of knowledge. In contrast, the claims with the highest acceptance rates, i.e., anthropogenic climate change, evolution, and vaccination, were more frequently connected with justifications referring to third entities or vaguely defined bodies of knowledge such as "studies" or "evidence".

Table 4. Proportions of justification types across the CSI topics.

Type of Justification	Evolution	Climate Change	GMF	Vaccination	SARS-CoV-2	N_{Total}
Subjective	0.4%	1.4%	7.3%	4.3%	3.6%	66
Deferential: Body of knowledge	49.1%	55.2%	25.3%	45.9%	26.1%	644
Deferential: Lack of knowledge	9.1%	5.9%	38.0%	6.5%	13.8%	230
Evidential: Theoretical	17.1%	6.2%	3.0%	12.3%	1.5%	132
Evidential: Empirical	20.6%	31.4%	26.3%	31.1%	55.0%	526
N_{Total}	350	290	300	325	333	1598

Compared with theoretical justifications, empirical justifications were far more common. However, this varied across the topics; while justifications concerning evolution relied almost equally on theoretical considerations and real-world observations, positions on SARS-CoV-2 were more frequently justified by empirical justifications.

Subjective justifications were the least common justification type, with the topic of GMF showing the highest proportion of subjective justifications, while almost no respondents gave subjective justifications in the contexts of evolution and anthropogenic climate change. The most frequent justification type overall was reference to a body of knowledge. This type was especially common when justifying attitudes on anthropogenic climate change, evolution, and vaccination.

In most cases, the acceptance of claims concerning the five different CSI topics did not correlate significantly with the identified type of justification (Table 5). However, the use of subjective justifications is negatively correlated to the acceptance of four of the CSI topics with a weak effect. The claim about GMF is the only one without a significant correlation to one of the justification types. Additionally, the acceptance of the effectiveness and safety of vaccines is significantly and weakly related to the use of deferential justifications referring to a body of knowledge.

Table 5. Correlation after Pearson between justification type and acceptance of scientific consensus on each topic. $N = 398$, * $p < 0.05$, ** $p < 0.01$.

Justification Type	Evolution	Climate Change	GMF	Vaccination	SARS-CoV-2
Subjective	−0.141 **	−0.175 **	−0.064	−0.186 **	−0.153 *
Deferential: Body of Knowledge	0.044	0.060	0.114	0.128 *	0.110
Deferential: Lack of Knowledge	0.045	0.015	−0.048	−0.008	0.044
Evidential: Theoretical	0.059	−0.003	0.057	−0.015	−0.026
Evidential: Empirical	0.056	−0.036	−0.074	−0.016	0.053

In general, the participants were not very religious ($M = 1.62$; $SD = 1.05$, score range: 1–5), were partly drawn to conspiracy theories ($M = 2.41$; $SD = 0.88$, score range: 1–5), and showed a high knowledge about NOS ($M = 4.69$; $SD = 0.44$, score range: 1–5).

A significant positive and strong correlation between the general acceptance of scientific consensus and knowledge about NOS ($N = 252$; $r = 0.558$; $p < 0.01$) was identified. Religiousness ($N = 254$; $r = -0.469$; $p < 0.01$) and conspiracy ideation ($N = 258$; $r = -0.655$; $p < 0.01$) correlated significantly negatively with the acceptance of scientific consensus with a medium (religiousness) to strong (conspiracy ideation) effect size.

Correlations of these variables with different types of justification were not significant in most cases (Table 6). Solely the use of subjective justifications (e.g., natural fallacy) correlated positively and weakly with the rejection of scientific consensus as well as negatively and weakly with conspiracy ideation. References to a body of knowledge correlated with the acceptance of scientific consensus with a weak effect. Furthermore, religiousness correlated weakly with the use of empirical justifications.

Table 6. Correlations between justification type and knowledge about NOS, religiousness, conspiracy ideation, and general acceptance of scientific consensus operationalized by the mean of acceptance of the claims on the five CSI topics. $N = 398$, * $p < 0.05$, ** $p < 0.01$.

Justification Type	NOS	Religiousness	Conspiracy Ideation	Acceptance of Scientific Consensus
Subjective	−0.045	0.029	0.180 **	−0.185 **
Deferential: Body of Knowledge	0.035	−0.121	0.102	0.102 *
Deferential: Lack of Knowledge	−0.024	0.009	0.030	0.020
Evidential: Theoretical	0.011	0.047	−0.036	0.007
Evidential: Empirical	0.032	0.184 **	0.079	−0.009

5. Discussion

The relatively high agreement with the claims on the different CSI indicates that most citizens who responded to the survey accept the respective scientific consensuses. However, while evolution as the explanation for the variety of life forms is accepted by more than 95% of the sample, only 57.5% agreed with the safety of GMF, the claim with the highest frequency of rejection and uncertainty. About 10% disagreed with the claims about the effectiveness and safety of vaccines and the health threat of SARS-CoV-2. Analysis of justifications resulted in five types of justifications for claims on CSI, each with several subtypes (RQ1). Justification types seem to be partly topic specific (RQ2) and in most cases are unrelated to whether the claim on a CSI was accepted or rejected (RQ3), as well as to variables like NOS, religiousness, and conspiracy ideation (RQ4).

5.1. Justification Types in the Field of Controversial Science Issues (RQ1)

To identify types of justifications in the field of CSI, we applied a deductive-inductive approach based on an existing justification coding scheme [36]. We identified subjective justifications that have been described before [36], sometimes referred to as normative justifications [27]. This type relies on individual spiritual, political, or ideological beliefs as well as on reasoning fallacies like *argumentum ad hominem*.

All justifications that could be identified as intersubjective formed a group that was further categorized. The distinction between references to a third entity (i.e., deferential) and references to the subject of discussion itself (i.e., evidential) was drawn from previous research [36] and applied to the data in this study. This common distinction can also be found in Shtulman [83].

However, taking a closer look at the deferential justifications, we distinguished references to a body of knowledge (e.g., “There is evidence for x”) from references to a lack of knowledge (e.g., “There is no evidence”). Another step toward more fine-grained categories was the distinction within the evidential category between empirical and theoretical justifications. Empirical justifications rely on real-world phenomena or precisely named and therefore provable data (e.g., correlation: "There is a positive correlation between greenhouse gas emissions and rising global temperature"), while theoretical justifications include a warrant to support the conclusion (e.g., cost risk calculation: "Even if climate change is not anthropogenic, we should assume it is. Better safe than sorry"). This categorization of the evidential justifications as either empirical or theoretical is therefore aligned with the distinction between data and warrant in TAP [32]. Furthermore, both types of evidential justifications share commonalities with components of scientific reasoning, e.g., the subskill of interpreting data [20] or abductive reasoning [93]. It would be worth investigating to what extent these types of evidential justifications align with the epistemic dimension of scientific reasoning as described by Osborne [21], referring to the questions "How do we know or how can we be certain?" [21] (p. 270).

Clearly, evidential justifications that refer to the CSI topic under consideration itself are highly topic-dependent. Due to the high diversity of SSI [70], a further generalization of this type of justification is challenging. One step that enabled the categorization into justification types was the focus on CSI as a special variant of SSI. Following Kolstø [94], who defined the field of risk-based SSI, and Borgerding and Dagistan [11] (see Figure 1), who differentiated between different fields as foundations for SSI, the theoretical clarification of the field of CSI as well as the resulting category system may help to further clarify the different fields within the broad topic of SSI. This is likely necessary for a finer analysis of justifications that could perhaps be field-specific.

5.2. Topic-Specific Justifications (RQ2)

Despite the field-specific scope of the category system, indicated by the occurrence of all five justification types in all five CSI topics, the results show frequency differences among justifications concerning the five CSI. This finding supports earlier results with a similar methodological design [36], while results of studies investigating SSR instead suggest consistency of the SSR framework across different SSI contexts [8,69]. However, this contrast may be resolved by seeing the SSR framework as a field-specific tool that is applicable to different topics of SSI, comparable with the category system for the field of CSI presented here. Toulmin [32] has already emphasized the field-specificity of arguments.

Whereas subjective and evidential justifications appear to be more topic-specific, the most general justification types seem to be deferential justifications referring to a body or lack of knowledge, either personal or related to the scientific field. In fact, the vast majority of deferential justifications refer to the scientific field. However, as the participants were aware that they were part of a scientific survey, they may have tried to use appropriate and convincing arguments. Laypeople are often capable of using "public scientific arguments" [25].

5.3. Relationship between Acceptance of CSI and the Use of Different Justifications (RQ3)

Generally, correlations between the use of certain justifications and the acceptance of the scientific consensus on the different CSI were weak. Still, the use of subjective justifications correlated with a rejection of the scientific consensus on most CSI, except for the safety of genetically modified food. One possible explanation is that all kinds of fallacies (i.e., argumentum ad populum, argumentum ad hominem, naturalistic fallacy) are subjective justifications. This fallacious argumentation is known to be rather common when arguing against a scientific consensus [95]. Despite the only small number of subjective justifications in total, these correlations suggest that subjective justifications are more frequently formulated if people reject the scientific consensus on a CSI.

Deferential and evidential justifications seem to appear for both acceptance and rejection of the scientific consensus, indicated by the insignificant correlations between the use of these justifications and acceptance of the scientific consensus on the five CSI. The only exception is a significant and weak correlation between reference to a body of knowledge and acceptance of the effectiveness and safety of vaccinations, indicating less frequent use of this argument when being skeptical about vaccinations.

5.4. Relationship between NOS, Religiousness, and Conspiracy Ideation with the Use of Different Justifications (RQ4)

Concerning the relationship between justification types and other variables, increased knowledge about NOS did not correlate with a certain type of justification, an observation made previously concerning NOS and the structural quality of arguments [47]. Nevertheless, NOS is known to be able to positively influence argumentation skills on SSI topics [85,96].

While Lobato and Zimmerman [36] noted that justification strategies appear highly heterogeneous within an individual's argumentation, our research demonstrated that even across the spectrum of science rejection and acceptance, all different kinds of justifications appear. This is consistent with previous findings that point out similarities in argumentation on supernatural beliefs and scientific knowledge [83]. However, significant correlations indicate that reference to a body of knowledge is more likely when accepting the scientific consensus, while subjective justifications are more frequent in argumentations against the scientific consensus.

Furthermore, subjective justifications are more frequent in people with high conspiracy ideation. Religiousness correlated weakly and positively with the use of empirical justifications, suggesting that religiousness is not necessarily an obstacle to reasoning on scientific topics [43].

6. Conclusions and Outlook

The task of fostering reasoning and argumentation competency goes beyond formal education in school and university [4]. In general, citizens are expected to employ evidence-based reasoning on issues grounded in science to make decisions in their personal lives and in public policy [97]. People often have difficulty evaluating evidence, which is problematic for informal reasoning on public policy and personal choices [4]. One crucial reason that these everyday reasoning tasks are difficult is the easy generation of causal explanation and their resistance [4,98].

To equip citizens with the ability to weigh up arguments and evaluate evidence, a first step is knowledge about the different types of justifications they provide for their attitudes concerning certain CSI. The category system reflecting justification types provides insight into the diversity of argumentation patterns and can inform teachers and pre-service teachers about potential attitudes and justifications on CSI that they might encounter in their lessons. Previous studies emphasized the importance of the inclusion of multidisciplinary perspectives when negotiating complex societal issues like CSI [7,35]. This approach can be informed by the category system, which was built upon a wide variety of different justifications from a heterogeneous online sample. It could furthermore be a helpful tool for fostering *science media literacy*, described by Höttecke and Allchin [99] as a crucial goal of science education in the age of social media [99].

Moreover, the presented category system lays the groundwork for further research in this area. On one hand, it will be the starting point for similar research in formal education. On the other hand, knowledge about justification types and how they differ across different contexts enables the ability to choose the best contexts to integrate into science education contexts.

Additionally, the results may inform science communication researchers and practitioners about the acceptance of the scientific consensus on different CSI topics and common justifications in these contexts. This is important, since even media reports often have problems handling scientific information [19].

In future research, the fine-grained assessment of general attitudes toward SSI brought forward by Klaver and Walma van der Molen [67] could be combined with the method of measuring justifications toward scientific consensus on specific CSI proposed in this article to shed more light on the different justification types. Furthermore, a research design integrating a task on SSR would be beneficial, e.g., by using the QuASSR [65]. In general, further investigation of the category system and its justification types should include steps of further validation [100] as well as argumentation in a broader discussion context, as has been suggested by several scholars [32,33,72]. The current study involved a random sample recruited within social networks to collect a wide variety of justifications for creating the category system. However, this sampling led to a high dropout rate and lacks representativeness of the quantified results. Future studies may apply the category system to samples within controlled environments. Another important next step is the theoretical and empirical investigation of the alignment of scientific reasoning and informal reasoning on CSI and SSI.

The novel term CSI could—following further theoretical and empirical clarification—help bridge the gap between the mostly separated research areas of science education and science communication [18].

Author Contributions: Conceptualization, A.B.; methodology, A.B.; validation, A.B., L.M. and A.U.z.B.; formal analysis, L.M.; investigation, L.M.; resources, A.B. and A.U.z.B.; data curation, LM. and A.B.; writing—original draft preparation, L.M. and A.B.; writing—review and editing, A.B., A.U.z.B. and L.M.; visualization, A.B.; supervision, A.B. and A.U.z.B.; project administration, A.B. and A.U.z.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: The respondents agreed to data use for research.

Data Availability Statement: The datasets are not publicly available.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. OECD. OECD Future of Education and Skills 2030. OECD Learning Compass 2030. A Series of Concept Notes. Available online: http://www.oecd.org/education/2030-project/contact/OECD_Learning_Compass_2030_Concept_Note_Series.pdf (accessed on 18 July 2021).
2. Gauchat, G. Politicization of Science in the Public Sphere: A Study of Public Trust in the United States, 1974 to 2010. *Am. Sociol. Rev.* **2012**, *77*, 167–187. [CrossRef]
3. Liu, D.W.C. Science Denial and the Science Classroom. *CBE Life Sci. Educ.* **2012**, *11*, 129–134. [CrossRef] [PubMed]
4. Shah, P.; Michal, A.; Ibrahim, A.; Rhodes, R.; Rodriguez, F. What makes everyday scientific reasoning so challenging? *Psychol. Learn. Motiv.* **2017**, *66*, 251–299. [CrossRef]
5. Sadler, T.D. Informal reasoning regarding socioscientific issues: A critical review of research. *J. Res. Sci. Teach.* **2004**, *41*, 513–536. [CrossRef]
6. Zeidler, D.L.; Sadler, T.D.; Simmons, M.L.; Howes, E.V. Beyond STS: A research-based framework for socioscientific issues education. *Sci. Educ.* **2005**, *89*, 357–377. [CrossRef]
7. Romine, W.L.; Sadler, T.D.; Dauer, J.M.; Kinslow, A. Measurement of socio-scientific reasoning (SSR) and exploration of SSR as a progression of competencies. *Int. J. Sci. Educ.* **2020**, *42*, 2981–3002. [CrossRef]
8. Sadler, T.D.; Barab, S.A.; Scott, B. What do students gain by engaging in socioscientific inquiry? *Res. Sci. Educ.* **2007**, *37*, 371–391. [CrossRef]
9. Zeidler, D.; Sadler, T.; Applebaum, S.; Callahan, B. Advancing reflective judgment through socioscientific issues. *J. Res. Sci. Teach.* **2009**, *46*, 74–101. [CrossRef]
10. Rutjens, B.T.; van der Linden, S.; van der Lee, R. Science skepticism in times of COVID-19. *Group Process. Intergr. Relat.* **2021**, *24*, 276–283. [CrossRef]
11. Borgerding, L.A.; Dagistan, M. Preservice science teachers' concerns and approaches for teaching socioscientific and controversial issues. *J. Sci. Teach. Educ.* **2018**, *29*, 283–306. [CrossRef]
12. McComas, W.F. Controversial Science Issues. In *The Language of Science Education*, 1st ed.; McComas, W.F., Ed.; SensePublishers: Rotterdam, The Netherlands, 2014; p. 26. [CrossRef]
13. Hornsey, M.J.; Fielding, K.S. Attitude roots and Jiu Jitsu persuasion: Understanding and overcoming the motivated rejection of science. *Am. Psychol.* **2017**, *72*, 459–473. [CrossRef] [PubMed]
14. Sadler, T.D.; Zeidler, D.L. Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *J. Res. Sci. Teach.* **2009**, *46*, 909–921. [CrossRef]
15. Burns, T.W.; O'Connor, D.J.; Stocklmayer, S.M. Science communication: A contemporary definition. *Public Underst. Sci.* **2003**, *12*, 183–202. [CrossRef]

16. Eastwood, J.L.; Schlegel, W.M.; Cook, K.L. Effects of an Interdisciplinary Program on Students' Reasoning with Socioscientific Issues and Perceptions of Their Learning Experiences. In *Socio-Scientific Issues in the Classroom—Teaching, Learning and Research*, 1st ed.; Sadler, T.D., Ed.; Springer: Dordrecht, The Netherlands, 2011; pp. 89–126. [CrossRef]
17. Upmeier zu Belzen, A.; Beniermann, A. Naturwissenschaftliche Grundbildung im Fächerkanon der Schule. *Z. Padagog.* **2020**, *66*, 642–665.
18. Baram-Tsabari, A.; Osborne, J. Bridging science education and science communication research. *J. Res. Sci. Teach.* **2015**, *52*, 135–144. [CrossRef]
19. Bromme, R.; Goldman, S.R. The public's bounded understanding of science. *Educ. Psychol.* **2014**, *49*, 59–69. [CrossRef]
20. Hartmann, S.; Upmeier zu Belzen, A.; Krüger, D.; Pant, H.A. Scientific reasoning in Higher Education: Constructing and Evaluating the Criterion-Related Validity of an Assessment of Preservice Science Teachers' Competencies. *Z. Psychol.* **2015**, *223*, 47–53. [CrossRef]
21. Osborne, J. The 21st century challenge for science education: Assessing scientific reasoning. *Think. Ski. Creat.* **2013**, *10*, 265–279. [CrossRef]
22. Means, M.L.; Voss, J.F. Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cogn. Instr.* **1996**, *14*, 139–178. [CrossRef]
23. Jiménez-Aleixandre, M.P.; Erduran, S. Argumentation in Science Education: An Overview. In *Argumentation in Science Education: Perspectives from Classroom-Based Research*, 1st ed.; Erduran, S., Jiménez-Aleixandre, M.P., Eds.; Springer: Dordrecht, The Netherlands, 2007; Volume 35, pp. 3–27. [CrossRef]
24. Osborne, J.; Erduran, S.; Simon, S. Enhancing the quality of argumentation in school science. *J. Res. Sci. Teach.* **2004**, *41*, 994–1020. [CrossRef]
25. Endres, D. Science and public participation: An analysis of public scientific argument in the Yucca Mountain controversy. *Environ. Commun.* **2009**, *3*, 49–75. [CrossRef]
26. Gresch, H.; Schwanewedel, J. Argumentieren als naturwissenschaftliche Praktik. In *Biologiedidaktische Forschung: Erträge für die Praxis*, 1st ed.; Groß, J., Hammann, M., Schmiemann, P., Zabel, J., Eds.; Springer Spektrum: Berlin/Heidelberg, Germany, 2019; pp. 167–185. [CrossRef]
27. Jafari, M.; Meisert, A. Activating students' argumentative resources on socioscientific issues by indirectly instructed reasoning and negotiation processes. *Res. Sci. Educ.* **2019**, 1–22. [CrossRef]
28. Zohar, A.; Nemet, F. Fostering Students' Knowledge and Argumentation Skills Through Dilemmas in Human Genetics. *J. Res. Sci. Teach.* **2002**, *39*, 35–62. [CrossRef]
29. Khishfe, R. Explicit nature of science and argumentation instruction in the context of socioscientific issues: An effect on student learning and transfer. *Int. J. Sci. Educ.* **2014**, *36*, 974–1016. [CrossRef]
30. Sjöström, J.; Eilks, I. Reconsidering different visions of scientific literacy and science education based on the concept of Bildung. In *Cognition, Metacognition, and Culture in STEM Education*, 1st ed.; Dori, Y.J., Mevarech, Z.R., Baker, D.R., Eds.; Springer: Cham, Switzerland, 2018; pp. 65–88. [CrossRef]
31. Sampson, V.; Clark, D.B. Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Sci. Educ.* **2008**, *92*, 447–472. [CrossRef]
32. Toulmin, S.E. *The Uses of Argument*; Cambridge University Press: Cambridge, UK, 2003; (Original Publication in 1958).
33. Lazarou, D.; Erduran, S. "Evaluate What I Was Taught, Not What You Expected Me to Know": Evaluating Students' Arguments Based on Science Teachers' Adaptations to Toulmin's Argument Pattern. *J. Sci. Teach. Educ.* **2021**, *32*, 306–324. [CrossRef]
34. Henderson, B.J.; McNeill, K.L.; Gonzalez-Howard, M.; Close, K.; Evans, M. Key challenges and future directions for educational research on scientific argumentation. *J. Res. Sci. Teach.* **2017**, *55*, 5–18. [CrossRef]
35. Garrecht, C.; Reiss, M.J.; Harms, U. 'I wouldn't want to be the animal in use nor the patient in need'—The role of issue familiarity in students' socioscientific argumentation. *Int. J. Sci. Educ.* **2021**, 1–22. [CrossRef]
36. Lobato, E.J.; Zimmerman, C. Examining how people reason about controversial scientific topics. *Think. Reason.* **2019**, *25*, 231–255. [CrossRef]
37. Sadler, T.D.; Zeidler, D.L. The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Sci. Educ.* **2005**, *89*, 71–93. [CrossRef]
38. Drummond, C.; Fischhoff, B. Individuals with greater science literacy and education have more polarized beliefs on controversial science topics. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 9587–9592. [CrossRef]
39. Jang, S.M. Seeking congruency or incongruency online? Examining selective exposure to four controversial science issues. *Sci. Commun.* **2014**, *36*, 143–167. [CrossRef]
40. Evagorou, M.; Dillon, J. Introduction: Socio-scientific Issues as Promoting Responsible Citizenship and the Relevance of Science. In *Science Teacher Education for Responsible Citizenship*, 1st ed.; Evagorou, M., Nielsen, J., Dillon, J., Eds.; Contemporary Trends and Issues in Science Education; Springer: Cham, Switzerland, 2020; pp. 1–11. [CrossRef]
41. Zeidler, D.L. Socioscientific issues as a curriculum emphasis: Theory, research and practice. In *Handbook of Research on Science Education*; Lederman, N.G., Abell, S.K., Eds.; Routledge: New York, NY, USA, 2014; Volume 2, pp. 697–726.
42. Zeidler, D.L.; Herman, B.C.; Sadler, T.D. New directions in socioscientific issues research. *Discipl. Interdiscip. Sci. Educ. Res.* **2019**, *1*, 1–9. [CrossRef]

43. Beniermann, A. *Evolution–von Akzeptanz und Zweifeln- Empirische Studien über Einstellungen zu Evolution und Bewusstsein*, 1st ed.; Springer Fachmedien: Wiesbaden Germany, 2019; pp. 1–469.
44. Kahan, D.M. Climate-science communication and the measurement problem. *Political Psychol.* **2015**, *36*, 1–43. [CrossRef]
45. Eagly, A.H.; Chaiken, S. *The Psychology of Attitudes*; Harcourt Brace Jovanovich College Publishers: Fort Worth, TX, USA, 1993.
46. Betsch, C.; Schmid, P.; Heinemeier, D.; Korn, L.; Holtmann, C.; Böhm, R. Beyond confidence: Development of a measure assessing the 5C psychological antecedents of vaccination. *PLoS ONE* **2018**, *13*, e0208601. [CrossRef]
47. Christenson, N.; Rundgren, S.N.C. A framework for teachers' assessment of socio-scientific argumentation: An example using the GMO issue. *J. Biol. Educ.* **2015**, *49*, 204–212. [CrossRef]
48. Graf, D.; Soran, H. Einstellung und Wissen von Lehramtsstudierenden zur Evolution—Ein Vergleich zwischen Deutschland und der Türkei. In *Evolutionstheorie—Akzeptanz und Vermittlung im Europäischen Vergleich*, 1st ed.; Graf, D., Ed.; Springer: Berlin/Heidelberg, Germany, 2010; pp. 141–161. [CrossRef]
49. Dunlap, R.E.; McCright, A.M. A widening gap: Republican and Democratic views on climate change. *Environ. Sci. Policy* **2008**, *50*, 26–35. [CrossRef]
50. Kahan, D.M.; Wittlin, M.; Peters, E.; Slovic, P.; Ouellette, L.L.; Braman, D.; Mandel, G.N. The tragedy of the risk-perception commons: Culture conflict, rationality conflict, and climate change. *Temple Univ. Leg. Stud. Res. Pap.* **2011**, *26*, 1–31. [CrossRef]
51. Scott, S.E.; Inbar, Y.; Wirz, C.D.; Brossard, D.; Rozin, P. An overview of attitudes toward genetically engineered food. *Annu. Rev. Nutr.* **2018**, *38*, 459–479. [CrossRef] [PubMed]
52. Blancke, S.; Van Breusegem, F.; De Jaeger, G.; Braeckman, J.; Van Montagu, M. Fatal attraction: The intuitive appeal of GMO opposition. *Trends Plant Sci.* **2015**, *20*, 414–418. [CrossRef] [PubMed]
53. Rutjens, B.T.; Sutton, R.M.; van der Lee, R. Not all skepticism is equal: Exploring the ideological antecedents of science acceptance and rejection. *Pers. Soc. Psychol.* **2018**, *44*, 384–405. [CrossRef]
54. Rutjens, B.T.; van der Lee, R. Spiritual skepticism? Heterogeneous science skepticism in the Netherlands. *Public Underst. Sci.* **2020**, *29*, 335–352. [CrossRef]
55. Marques, M.D.; Kerr, J.R.; Williams, M.N.; Ling, M.; McLennan, J. Associations between conspiracism and the rejection of scientific innovations. *Public Underst. Sci.* **2021**, 1–14. [CrossRef]
56. Weisberg, D.S.; Landrum, A.R.; Hamilton, J.; Weisberg, M. Knowledge about the nature of science increases public acceptance of science regardless of identity factors. *Public Underst. Sci.* **2021**, *30*, 120–138. [CrossRef]
57. Shaw, V.F. The cognitive processes in informal reasoning. *Think. Reason.* **1996**, *2*, 51–80. [CrossRef]
58. Evans, J.S.B.T.; Thompson, V.A. Informal reasoning: Theory and method. *Can. J. Exp. Psychol.* **2004**, *58*, 69–74. [CrossRef] [PubMed]
59. Evans, J.S.B.T. Logic and human reasoning: An assessment of the deduction paradigm. *Psychol. Bull.* **2002**, *128*, 978–996. [CrossRef] [PubMed]
60. Kuhn, D. Connecting scientific and informal reasoning. *Merrill-Palmer Q.* **1993**, *39*, 74–103.
61. Wu, Y.T.; Tsai, C.C. High school students' informal reasoning on a socio-scientific issue: Qualitative and quantitative analyses. *Int. J. Sci. Educ.* **2007**, *29*, 1163–1187. [CrossRef]
62. Kolstø, S.D. Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Sci. Educ.* **2001**, *85*, 291–310. [CrossRef]
63. Zeidler, D.L.; Lewis, J. Unifying themes in moral reasoning on socioscientific issues and discourse. In *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education*, 1st ed.; Zeidler, D.L., Ed.; Springer: Dordrecht, The Netherlands, 2003; Volume 19, pp. 289–306.
64. Zeidler, D.L.; Nichols, B.H. Socioscientific issues: Theory and practice. *J. Elem. Sci. Educ.* **2009**, *21*, 49–58. [CrossRef]
65. Romine, W.L.; Sadler, T.D.; Kinslow, A.T. Assessment of scientific literacy: Development and validation of the Quantitative Assessment of Socio-Scientific Reasoning (QuASSR). *J. Res. Sci. Teach.* **2017**, *54*, 274–295. [CrossRef]
66. Eggert, S.; Bögeholz, S. Students' use of decision-making strategies with regard to socioscientific issues: An application of the Rasch partial credit model. *Sci. Educ.* **2010**, *94*, 230–258. [CrossRef]
67. Klaver, L.T.; Walma van der Molen, J.H. Measuring Pupils' Attitudes Towards Socioscientific Issues. *Sci. Educ.* **2021**, *30*, 317–344. [CrossRef]
68. Yang, F.Y.; Anderson, O.R. Senior high school students' preference and reasoning modes about nuclear energy use. *Int. J. Sci. Educ.* **2003**, *25*, 221–244. [CrossRef]
69. Sadler, T.D.; Klosterman, M.L.; Topcu, M.S. Learning Science Content and Socio-scientific Reasoning Through Classroom Explorations of Global Climate Change. In *Socio-Scientific Issues in the Classroom—Teaching, Learning and Research*, 1st ed.; Sadler, T.D., Ed.; Springer: Dordrecht, The Netherlands, 2011; pp. 45–77. [CrossRef]
70. Cian, H. The influence of context: Comparing high school students' socioscientific reasoning by socioscientific topic. *Int. J. Sci. Educ.* **2020**, *42*, 1503–1521. [CrossRef]
71. Topcu, M.S.; Sadler, T.D.; Yilmaz-Tuzun, O. Preservice science teachers' informal reasoning about socioscientific issues: The influence of issue context. *Int. J. Sci. Educ.* **2010**, *32*, 2475–2495. [CrossRef]
72. Driver, R.; Newton, P.; Osborne, J. Establishing the norms of scientific argumentation in classrooms. *Sci. Educ.* **2000**, *84*, 287–312. [CrossRef]
73. Siegel, H. Why should educators care about argumentation? *Inform. Log.* **1995**, *17*, 159–176. [CrossRef]

74. Schwarz, B.; Glassner, A. The blind and the paralytic: Supporting argumentation in everyday and scientific issues. In *Arguing to Learn: Confronting Cognitions in Computer-Supported Collaborative Learning Environments*, 1st ed.; Andriessen, J., Baker, M., Suthers, D., Eds.; Springer: Dordrecht, The Netherlands, 2003; Volume 1, pp. 227–260. [CrossRef]
75. Sandoval, W.A.; Millwood, K. The quality of students' use of evidence in written scientific explanations. *Cogn. Instr.* **2005**, *23*, 23–55. [CrossRef]
76. Paglieri, F. *Coding between the Lines: On the Implicit Structure of Arguments and Its Import for Science Education*; ISTC-CNR Roma; University of Siena: Siena, Italy, 2006.
77. Erduran, S.; Simon, S.; Osborne, J. TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Sci. Educ.* **2004**, *88*, 915–933. [CrossRef]
78. Koomen, H.M.; Rodriguez, E.; Hoffman, A.; Petersen, C.; Oberhauser, K. Authentic science with citizen science and student-driven science fair projects. *Sci. Educ.* **2018**, *102*, 593–644. [CrossRef]
79. McNeill, K.L.; Lizotte, D.J.; Krajcik, J.; Marx, R.W. Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *J. Learn. Sci.* **2006**, *15*, 153–191. [CrossRef]
80. Kelly, G.J.; Druker, S.; Chen, C. Students' reasoning about electricity: Combining performance assessments with argumentation analysis. *Int. J. Sci. Educ.* **1998**, *20*, 849–871. [CrossRef]
81. Kelly, G.; Takao, A. Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Sci. Educ.* **2002**, *86*, 314–342. [CrossRef]
82. Dawson, V.; Carson, K. Introducing argumentation about climate change socioscientific issues in a disadvantaged school. *Res. Sci. Educ.* **2018**, *50*, 863–883. [CrossRef]
83. Shtulman, A. Epistemic similarities between students' scientific and supernatural beliefs. *J. Educ. Psychol.* **2013**, *105*, 199–212. [CrossRef]
84. Khishfe, R. Relationship between nature of science understandings and argumentation skills: A role for counterargument and contextual factors. *J. Res. Sci. Teach.* **2012**, *49*, 489–514. [CrossRef]
85. Simonneaux, L. Argumentation in socio-scientific contexts. In *Argumentation in Science Education: Perspectives from Classroom-Based Research*, 1st ed.; Erduran, S., Jiménez-Aleixandre, M.P., Eds.; Springer: Dordrecht, The Netherlands, 2007; Volume 35, pp. 179–199. [CrossRef]
86. Basel, N.; Harms, U.; Prechtl, H.; Weiß, T.; Rothgangel, M. Students' arguments on the science and religion issue: The example of evolutionary theory and Genesis. *J. Biol. Educ.* **2014**, *48*, 179–187. [CrossRef]
87. Agley, J. Assessing changes in US public trust in science amid the COVID-19 pandemic. *Public Health* **2020**, *183*, 122–125. [CrossRef] [PubMed]
88. Urhahne, D.; Kremer, K.; Mayer, J. Conceptions of the nature of science—are they general or context specific? *Int. J. Sci. Math. Educ.* **2011**, *9*, 707–730. [CrossRef]
89. Beniermann, A.; Kuschmierz, P.; Pinxten, R.; Aivelo, T.; Bohlin, G.; Brennecke, J.S.; Cebesoy, U.B.; Cvetković, D.; Đorđević, M.; Dvořáková, R.M.; et al. Evolution Education Questionnaire on Acceptance and Knowledge (EEQ) - Standardised and ready-to-use protocols to measure acceptance of evolution and knowledge about evolution in an international context. *Zenodo* **2021**. [CrossRef]
90. Bruder, M.; Haffke, P.; Neave, N.; Nouripanah, N.; Imhoff, R. Measuring individual differences in generic beliefs in conspiracy theories across cultures: Conspiracy Mentality Questionnaire. *Front. Psychol.* **2013**, *4*, 1–15. [CrossRef] [PubMed]
91. Mayring, P. *Qualitative Inhaltsanalyse*, 12th ed.; Beltz: Weinheim, Germany, 2015.
92. O'Connor, C.; Joffe, H. Intercoder Reliability in Qualitative Research: Debates and Practical Guidelines. *Int. J. Qual. Methods* **2020**, *19*, 1–13. [CrossRef]
93. Upmeier zu Belzen, A.; Engelschalt, P.; Krüger, D. Modeling as Scientific Reasoning—The Role of Abductive Reasoning for Modeling Competence. *Educ. Sci.* **2021**, *11*, 495. [CrossRef]
94. Kolstø, S.D. Patterns in students' argumentation confronted with a risk-focused socio-scientific issue. *Int. J. Sci. Educ.* **2006**, *28*, 1689–1716. [CrossRef]
95. Zeidler, D.L.; Osborne, J.; Erduran, S.; Simon, S.; Monk, M. The role of argument during discourse about socioscientific issues. In *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education*, 1st ed.; Zeidler, D.L., Ed.; Springer: Dordrecht, The Netherlands, 2003; Volume 19, pp. 97–116.
96. Khishfe, R. Explicit Instruction and Student Learning of Argumentation and Nature of Science. *J. Sci. Teach. Educ.* **2021**, *32*, 325–349. [CrossRef]
97. Kuhn, D.; Lerman, D. Yes but: Developing a critical stance toward evidence. *Int. J. Sci. Educ.* **2021**, *43*, 1036–1053. [CrossRef]
98. Glassner, A.; Weinstock, M.; Neuman, Y. Pupils' evaluation and generation of evidence and explanation in argumentation. *Br. J. Educ. Psychol.* **2005**, *75*, 105–118. [CrossRef]
99. Höttecke, D.; Allchin, D. Reconceptualizing nature-of-science education in the age of social media. *Sci. Educ.* **2020**, *104*, 641–666. [CrossRef]
100. American Educational Research Association (AERA); American Psychological Association (APA); National Council on Measurement in Education (NCME). *Standards for Educational and Psychological Testing*; American Educational Research Association: Washington, DC, USA, 2014.