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Investigating the Knowledge Domains Science Teachers Use When Considering a Socioscientific Issue

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Abstract

In an increasingly complex media environment, science educators must help prepare students to make decisions on science-related issues that are in the best interest of themselves and their communities. Researchers have suggested the use of socioscientific issues (SSI) to teach students how to think scientifically and to make good decisions regarding science-related issues. To support students in their learning, growth, and thinking when considering SSI, it is helpful to know how people think about SSI. Understanding the knowledge domains that people draw from when considering SSI will help researchers and teachers support students in their thinking and decision-making regarding SSI. Many studies have looked at how people use individual knowledge domains, but few have looked at multiple knowledge domains in concert. This study investigated the knowledge domains that secondary science teachers use when considering a regional SSI. Participants were interviewed using a think-aloud protocol, in which they read an article about an SSI and were asked to verbalize their thinking about the issue. Findings indicate that participants in our study drew most often from the domains of media literacy and the nature of technology (NOT). We suggest that such domains deserve more attention than they have received in science classrooms if students are to be more fully prepared to engage with SSI.

Keywords Socioscientific issues · Knowledge domains · Nature of technology · Media literacy

In an increasingly complex media environment, science educators must help prepare students to make decisions on science-related issues. Sadler, (2004a) argued scientifically literate individuals solve problems, confront issues, and make informed decisions

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using scientific processes and habits of mind. To support scientific literacy development, researchers suggest instruction using socioscientific issues (SSI) (Sadler, 2004b). To better prepare students for engaging in SSI, this study sought to understand what knowledge domains in-service science teachers use when considering SSI. Understanding the knowledge domains people draw from when considering SSI will help researchers and teachers more directly target the conceptual support students may need to enhance their thinking regarding SSI.

Conceptual Framework

Science teachers can support the development of students' scientific literacy through the use of SSI. SSI are "[c]omplex social issues with conceptual and/or technological associations with science" (Sadler et al., 2004, p. 513). With SSI, students are asked to consider multiple perspectives and courses of action on a particular science-related social issue. A single course of action is unlikely to benefit all stakeholders; thus, students learn to navigate the complexity of the real world (Owens et al., 2021). As a result, SSI in the science classroom provides a useful avenue for promoting scientific thinking, quality decision-making, and understanding of relevant science content (Ke et al., 2021; Zeidler & Sadler, 2011). In addition, SSI inclusion improves students' science content learning (Barab et al., 2007; Dori et al., 2003; Sadler et al., 2016), communication skills (Chung et al., 2016), and nature of science (NOS) understanding (Wong et al., 2011).

Research continues to investigate how people engage with SSI. Many researchers have analyzed knowledge domains (e.g., science content knowledge, NOS, etc.) that various populations draw on when considering an SSI. Below is a brief discussion of findings related to each knowledge domain as found in the literature.

Science Content Knowledge

Science content knowledge includes the concepts and principles currently accepted about the natural world. Such knowledge is necessary to make informed decisions about complex societal problems (DeBoer, 2000; Lindahl & Lundin, 2016); thus, curriculum documents (e.g. AAAS, 1989; NRC, 1996; NRC, 2012) have always included content dimensions and scholars have analyzed the relationship between content knowledge and reasoning regarding SSI. Fowler and Zeidler, (2016) found that undergraduate biology and non-biology majors generally utilize content knowledge when thinking about biology-based SSI (e.g., cloning, gene therapy, and preventative antibiotics), and science undergraduate students with stronger content knowledge have fewer instances of flawed reasoning (Sadler & Zeidler, 2005). In contrast, Sadler and Donnelly, (2006) found that high school students from the southeastern United States rarely used content knowledge in their discussions of genetic engineering issues, but rather drew from science fiction knowledge. Lindahl and Lundin, (2016) noted high school students' application of content knowledge when engaging in various SSI regarding human sexuality was dependent on the complexity of the issue—students relied less on science content knowledge as the complexity of the issue grew.

Personal Experience

Personal experience refers to knowledge acquired through interactions with their family, friends, community, and/or culture. Science educators have long acknowledged the role of students' personal experiences in making sense of scientific phenomena. Students' funds of knowledge (Gonzalez & Moll, 2001) provide a base on which students can build. Personal experience is widely recognized as influencing reasoning regarding SSI (Lindahl & Lundin, 2016), but this influence may vary across contexts—such as topic and culture—(Sadler, 2004b) and Zeidler et al., (2002) found that high school students and students in a preservice elementary science methods course sometimes compartmentalized their personal experiences from scientific beliefs when considering research conducted on animals.

Domain-Specific Epistemological Beliefs and the Nature of Science

Knowledge of NOS, or knowledge about how science and scientists work as well as the interactions between science and society, is argued to be integral to the development of scientific literacy (NRC, 2012) but there is limited evidence that NOS views impact decision-making on SSI. Bell and Lederman, (2003) presented science college professors with four different SSI: fetal tissue implantation, global warming, the relationship between diet and cancer, and the relationship between smoking and cancer. They found few notable differences in participants' decision-making on SSI across various NOS views. Even when individuals understand NOS, they do not typically seem to draw on that understanding when reasoning about SSI. Walker and Zeidler, (2003) found that even when high school students recognized the uncertainty of scientific predictions, the tentative nature of science, and the importance of sound evidence, there was not a clear connection between NOS and their arguments in relation to genetically modified foods. Likewise, Khishfe et al., (2017) noted that high school students with more informed views of NOS had more well-developed arguments, but those arguments were not clearly connected to aspects of NOS. Similarly, Wu and Tsai, (2011) found high school students' beliefs about the justification of scientific knowledge were correlated with reasoning quality, but did not necessarily find participants use NOS in their reasoning regarding nuclear power usage. Thus, although a connection between NOS and reasoning on SSI is suspected, this connection is not yet well-supported empirically.

Domain-General Epistemological Beliefs

Domain-general epistemological beliefs include "beliefs about the certainty of knowledge, the organization of knowledge, and the control individuals have over their own knowledge acquisition" (Schommer-Aikins & Hutter, 2002, p. 6). Domain-general epistemological beliefs are connected to an individual's comprehension of information related to difficult academic tasks (Schommer-Aikins & Hutter, 2002), and thus might be expected to influence SSI reasoning. Schommer-Aikins and Hutter, (2002) studied a random sample of adults and found beliefs in the complexity and tentative nature of knowledge were positively correlated to more flexible, multifaceted thinking about a wide range of contemporary controversial issues. More recently, Baytelman et al., (2020) presented pre-service elementary teachers enrolled in a science education course with three different scenarios: (1) usage of vaccines against the NUEVO flu virus, (2) consumption of bottled vs tap water, and (3) usage of underground vs overhead high voltage lines. They found that participants who held epistemic beliefs the researchers considered sophisticated developed more arguments of better quality and higher diversity.

Morals/Values/Ethics

SSI are inherently value-laden, and thus morals influence thinking about SSI. Morals and ethics are "factors related to an individual's determination of what is right, good, and virtuous" (Sadler & Donnelly, 2006, p. 1467). Bell and Lederman, (2003) found that science college professors' personal values were more likely to influence their decision-making about various SSI than NOS beliefs (as described above). Sadler and Donnelly, (2006) found that participants often used concepts of good/bad or right/wrong when thinking about genetic technologies, often stemming from religious beliefs. They also observed many participants state they would leave moral issues up to the personal ethics of each individual when confronted with counter-points to their own arguments to avoid further argumentation.

Economics

Economic knowledge entails the consideration of finances from the perspective of an individual, business, or nation. Researchers have noted the relevance of economics to a holistic view of SSI (Chang Rundgren & Rundgren, 2010; Dani, 2011; Sadler, 2004b; Tsai et al., 2019), and there is evidence that individuals at least occasionally utilize economics to justify their stance on SSI (Christenson et al., 2012; 2014; Dani, 2011). Christenson et al., (2014) found that science and non-science college students use economics knowledge more frequently during discussion of consumption. More recently, Owens et al., (2021) found STEM and non-STEM undergraduate students use economics knowledge when engaging with some dimensions (e.g., complexity, skepticism, engaging with multiple perspectives, and recognizing the on-going inquiry of SSI) of socioscientific reasoning (SSR) while considering an issue regarding river pollution.

Sociology

Sociology refers to knowledge regarding society and public entities. Researchers in the SSI field have long acknowledged sociological aspects of SSI, such as diversity in race, gender, and culture (Zeidler & Keefer, 2003; Zeidler et al., 2005), but there is limited research into how individuals use sociology knowledge when considering SSI. Owens et al., (2021) found that STEM and non-STEM undergraduate students typically referred to public health, public opinion, diversity, and cooperation when considering river pollution. However, it seems that individuals use sociology to justify their decisions relatively infrequently (Christenson et al., 2012, 2014; Karisan & Cebesoy, 2021).

Psychology

Whereas the sociology domain targets the way that groups of people interact, the psychology domain considers the way people think on an individual level. Unfortunately, little research has been done on the use of psychology when considering SSI. Owens et al., (2021) found that undergraduate students use some psychology knowledge when engaging in SSR. However, individuals' use of psychology knowledge was not common. When using psychology knowledge, individuals tended to note individuals with different values do not always agree.

Politics

Broadly conceptualized as policy and government considerations, politics is another domain with little attention in SSI literature. Owens et al., (2021) found that undergraduate students frequently applied knowledge of politics when engaging in the complexity and perspective-taking dimensions of SSR within the context of river pollution. Students mostly applied knowledge related to government regulation.

Media Literacy

Media literacy includes knowledge related to creation of media (e.g., newspaper and television), professional roles/responsibilities of journalists, purposes of journalistic content, and constraints of journalistic endeavors. People who are not scientists depend heavily on various media to make decisions about socioscientific issues (Jarman & McClune, 2007; Reid & Norris, 2016). Namdar et al., (2020) studied the relationship between media literacy and informal SSI reasoning and found a correlation between pre-service science teachers' media literacy and their informal reasoning quality regarding the use of hydroelectric power. Dani et al., (2010) found that while science preservice teachers considered the quality of arguments presented, readability, authority, and bias when evaluating information on the web, they did not seem to ascribe more accuracy, authority, or bias to any specific type of website when considering an SSI of interest to each participant.

Nature of Technology

The nature of technology (NOT) domain draws heavily from what Mitcham (1994) calls the humanities philosophy of technology. NOT focuses on questions such as the following: What is technology? What are the trade-offs for a given technology? How does technology affect how people think and act? How is technology limited? How does technology impact society? (DiGironimo, 2011; Herman, 2013; Kruse, 2013a; Kruse et al., 2017; Kruse & Wilcox, 2013; Pleasants et al., 2019). NOT understanding "equips students to more carefully consider implications of technology in their personal lives…and in society" (Kruse et al., 2017, p. 42) and Clough, (2013) argued that knowledge of NOT is a key aspect of socioscientific decision-making. While some have noted the importance of teaching the NOT in K-12 schools, more research is needed to explore the impact of NOT views on decision-making (Pleasants et al., 2019).

Multiple Domains

We have reviewed knowledge domains observed when thinking about SSI but acknowledge people are likely to draw on multiple domains simultaneously. Several researchers have used the SEE-SEP model (Chang Rundgren & Rundgren, 2010) to analyze individuals' thinking regarding SSI with respect to multiple domains. The SEE-SEP model includes six subject areas (sociology, environment, economy, science, ethics/morals, and policy) in order to look at SSI in a more holistic way. It seems that individuals justify their opinions on various SSI using knowledge of the six subjects of the SEE-SEP to varying degrees (Christenson et al., 2012; 2014). Karisan and Cebesoy, (2021) found that when considering genetics-related SSI, pre-service science teachers largely drew on ethics/morality and science content knowledge while using sociology and economics knowledge infrequently. While the SEE-SEP provides valuable information regarding the use of multiple knowledge domains, it typically asks participants to choose sides and defend their choice. Such an approach may be limited to understanding how people defend their choices with respect to SSI.

The Quantitative Assessment of Socio-Scientific Reasoning (QuASSR) (Romine et al., 2017) has also been used to investigate knowledge domains for SSR. Owens et al., (2021) used the QuASSR to study what knowledge domains undergraduates from various environmental science classes use when considering two local SSI regarding fracking and land management. The researchers used domains derived from the SSR literature base and found that participants drew from economics, ethics, politics, psychology, and science, but the frequency with which participants used each knowledge domain was dependent on the SSR dimension in which they were engaged. Although the QuASSR has demonstrated clear utility in revealing participants' reasoning, the written and structured nature of the QuASSR may limit the insight afforded. Indeed, Owens et al., (2021) proceeded to call for alternative research methods to highlight the breadth of knowledge domains that students rely on.

Purpose of Study and Research Questions

Our study seeks to build upon the work of the SEE-SEP model and Owens et al., (2021) using a think-aloud protocol to collect data on individuals' thinking regarding SSI and to highlight the breadth of the knowledge domains that participants use when considering an SSI. This open-ended, naturalistic approach may reveal new insights about the knowledge domains from which participants draw when reading about an SSI. Specifically, this study sought to answer the following questions:

1. What knowledge domains do in-service secondary science teachers use when considering an SSI?
2. To what extent is each knowledge domain used?

Methodology

This study most closely aligns with naturalistic inquiry. Exploratory in nature, naturalistic inquiry studies a phenomenon in its natural environment because the phenomenon is inextricably connected to the context in which it occurs (Lincoln & Guba, 1985). Because people generally encounter information about science-related issues via media outlets, this study involved asking participants to think out loud as they read an online article about a SSI on a digital device. Rather than requiring a structured instrument (e.g., QuASSR) or fitting participants' thinking into a pre-existing framework (e.g., SEE-SEP), we encouraged participants to verbalize their thinking during an authentic task and sought evidence for a variety of knowledge domains identified in the literature.

Participants

Participants for this study were recruited through the researchers' personal networks. After receiving approval from the Institutional Review Board (IRB), the researcher emailed twelve in-service secondary science teachers to ask if they would be willing to participate in the study. Participants were told that they would be asked to read an article about a science-related issue and explain their thinking. The researchers emphasized that the intent was not to evaluate or judge participant responses, but rather to see how practicing teachers think about such things. Ten teachers agreed to participate.

The ten secondary science teachers who opted to participate in the study were all from the US Midwest region and attended the same medium-sized Midwestern University. Participants consisted of four males and six females, of which all were white. As part of their teacher preparation program, participants took courses on general science methods, nature of science, and nature of technology. Participants all had between 1 and 5 years of teaching experience and resided within the Midwestern United States at the time of interviewing.

Data Collection

Data was collected through interviews utilizing a think-aloud protocol (Van Someren et al., 1994). The think-aloud protocol allowed researchers to observe individuals in a natural setting—an encounter with an SSI in a news media article online. Researchers have argued that the think-aloud protocol is an effective method for collecting data about individuals' experiences (Birns et al., 2002; Bowen, 1994) and elicits information about thinking that other more targeted forms of data collection cannot (Charters, 2003; Van Someren et al., 1994). Thus, using a think-aloud protocol may lead to data that more authentically represents participants' thinking regarding the knowledge domains they draw from when considering an SSI.

Each interview for this study was conducted by one of two researchers. Researcher 1 is a graduate student in science education. Researcher 2 is a science teacher at an American Midwest suburban high school with an undergraduate degree in secondary education. Both researchers attended the same teacher preparation program as study participants. In some cases, participants were already known to the researchers prior to the start of the study. Since the think-aloud protocol requires the interviewer to interact with participants minimally, familiarity between researchers and participants was not viewed as problematic.

All interviews were conducted and recorded via video call. Once the participant and interviewer were on a call, participants were emailed an electronic copy of an article published by *Vox* titled, *How America Got Addicted to Road Salt—and Why It's Become a Problem* (Plumer, 2015). The article discusses problems with road salt and attempts to resolve those problems. Participants were instructed to "think out loud" while reading the article. Stopping points were added to the article to further prompt participants to share their thinking (Charters, 2003). As participants read through the article and thought out loud, interviewers would interject with questions (e.g. "What are you thinking now?" "Can you elaborate?") only when participants were silent or too vague in order to gather information on participant thinking (e.g., Bowen, 1994). During the interview, participants would often ask if they were supposed to think about the article from the lens of a teacher or from the lens of a citizen. When asked, interviewers would tell participants to verbalize any thoughts that came up regardless of the lens. Interviews lasted 28 min on average.

Data Analysis

Each interview was transcribed by the primary researcher. Once transcribed, the text of each interview was divided into segments accounting for a separate yet cohesive thought. Data was divided to make more manageable segments to code and thereby organize participant responses. A segment was categorized as a single thought based on three criteria: (1) the participant finished speaking and continued reading the article, (2) the interviewer asked a question prompting elaboration or more input from the participant, or (3) the participant clearly switched topics without making a connection to previous thinking. This process resulted in 396 data segments.

Individual segments were analyzed qualitatively through the use of provisional codes (Saldaña, 2013). Provisional codes reflected the knowledge domains previously identified in the conceptual framework (e.g., science content and NOS). Each segment was coded based on the knowledge domain(s) that participants drew from in that particular segment. Thus, several codes could be applied to one segment. Data was fully coded by one researcher, and a second researcher (graduate student in science education) coded 45% of the data with 98% agreement between the two researchers.

Codes were counted to aid in comparisons across domains. Each participants' total data segments were counted as well. For each participant, the number of times a particular code was observed was divided by the total number of data segments to calculate the percentage in which a particular code was used. Use of percent allows us to compare across participants more effectively while accounting for the fact that some participants said more than others.

Results

Participants used each knowledge domain to some extent, as depicted in Table 1. The top number in each cell of Table 1 indicates the total number of codes each participant had for each knowledge domain, and the percentage represents the number of times the participant used a certain knowledge domain relative to the total number of data segments for that participant. The average percent was calculated by averaging the percent of each domain across participants. As observed in Table 1, the most common knowledge domains that participants in our study drew from were media literacy, the nature of technology (NOT), and economics. An example quote for each code appears in Table 2.

Discussion

Our study corroborates existing literature by demonstrating that individuals draw on several knowledge domains in concert when considering an SSI (Christenson et al., 2012; Christenson et al., 2014; Lindahl & Lundin, 2016; Owens et al., 2021). However, while participants in this study drew on a variety of knowledge domains, they rarely made connections to psychology, domain-general epistemological beliefs, or NOS when thinking about the road salt issue. Participants' limited use of NOS is consistent with the findings of

Table 1 Results of knowledge domain coding

Participant	Media literacy	NOT	Economics	Sociology	Personal knowledge	Content knowledge	Morals /ethics	Politics	Psychology	NOS	DGE*	Total codes
A	14 (29%)	12 (26%)	5 (11%)	4 (8%)	2 (4%)	8 (17%)	2 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	47
B	17 (55%)	2 (6%)	2 (6%)	3 (10%)	3 (10%)	2 (6%)	1 (3%)	0 (0%)	0 (0%)	1 (3%)	0 (0%)	31
C	4 (17%)	4 (17%)	2 (9%)	5 (22%)	2 (9%)	2 (9%)	3 (13%)	1 (4%)	0 (0%)	0 (0%)	0 (0%)	23
D	0 (0%)	5 (13%)	6 (15%)	7 (18%)	10 (26%)	6 (15%)	1 (3%)	3 (8%)	1 (7%)	0 (0%)	0 (0%)	39
E	16 (31%)	14 (27%)	9 (17%)	3 (6%)	1 (2%)	4 (8%)	1 (2%)	0 (0%)	3 (2%)	1 (2%)	0 (0%)	52
F	13 (17%)	20 (26%)	10 (13%)	7 (9%)	7 (9%)	3 (4%)	5 (6%)	5 (6%)	1 (1%)	6 (8%)	1 (1%)	78
G	7 (21%)	9 (27%)	3 (9%)	3 (9%)	5 (15%)	0 (0%)	5 (15%)	1 (3%)	0 (0%)	0 (0%)	0 (0%)	33
H	3 (8%)	7 (19%)	7 (19%)	4 (11%)	2 (6%)	5 (14%)	3 (8%)	2 (6%)	2 (5%)	1 (3%)	0 (0%)	36
I	6 (26%)	7 (30%)	5 (22%)	0 (0%)	0 (0%)	1 (4%)	4 (17%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	23
J	9 (26%)	8 (24%)	3 (9%)	5 (15%)	6 (18%)	3 (9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	34
Average percent	23%	22%	13%	11%	10%	9%	7%	3%	2%	2%	0%	——

*Domain-general epistemological beliefs.

Table 2 Results of knowledge domain coding

Code	Example quote(s)
Media Literacy	Is there- am I just not seeing it- is there, like, a 'fact-check section' where it actually has like where some of these statistics come from? (B)
NOT	So I like to personally think about systems, think of things in systems, and then identify what are the mechanics in them and what are the tradeoffs that are in those. So I like this paragraph that talks about um, the highway expansion and um, our reliance on um, truckers and commuters and how that's why we have such a need for this salt is because we have a need for clean roads because we value the highways in all of this (A)
Economics	…we're paying all this money in the first place to clean this up, 2.3 billion dollars is a ton of money to do that. But then also we have to pay double that from like a society standpoint, just to clean up what we've just always really used (E)
Sociology	Like oftentimes, the person will need to like pay for a recycling bin in order to recycle and so if you are a member of a low socioeconomic group, you are not going to use your dispensary income to pay for a recycling thing. (G)
Personal Knowledge	I'm a Wisconsin girl. You gotta pre-salt or you're screwed. I lived in Iowa for six years where they salt when the like, when the storm has passed and that leads to awfulness. But that's also my own bias like I can admit that (B)
Content Knowledge	…you could even go down to like the membrane level and talk about osmosis and diffusion and use that to try to understand why salt in an ecosystem is bad or how it affects the whole ecosystem and changes it potentially for the worst (F)
Morals/Ethics	Um, I would say it gives me a greater bias in the way I weigh the negatives. Um I tend to- in my mind- lean towards protecting the environment and long-term planning rather than short-term economy (H)
Politics	Because I'm a taxpayer and I pay property taxes and if the city… wants to get these, where's that money gonna come from? (D)
Psychology	2% of U.S. drinking water wells studied had chloride levels higher than the EPA's recommended threshold. I feel like that's a really low number and that if the article is trying to get people to um be concerned about it, I feel like that may be the opposite effect, of well oh it's only 2% so we're fine (E)
NOS	…like this would probably be the best section I would say because it has so much scientific evidence and like actual reports and data to kind of back up what it wants to say. I feel like that makes its argument more well-rounded (A)
Domain-general Epistemological Beliefs	Like I said I was skeptical but if there's actual evidence in here I'll become less skeptical… So yeah I have no idea what the mechanism is there. Um, maybe as a person who is generally curious about like how things work, this answer is not satisfying my curiosity (F)

other studies on NOS and SSI (Khishfe et al., 2017; Walker & Zeidler, 2003; Zeidler et al., 2002). Instead, participants in this study most often drew on their knowledge of media literacy and NOT. To the extent that we are aware, this study is the first to empirically demonstrate such emphasis on NOT and media literacy in the context of SSI. Each of these is discussed further below.

Role of Media Literacy in SSI

In this study, we observed that while thinking about an SSI, participants considered aspects of media (e.g., author credibility, journalistic integrity). This finding is consistent with previous work examining the relationship between media and SSI. Namdar et al., (2020) suggest that improvements in media literacy could be one way to improve the quality of individuals' socioscientific decision-making. In the age of social media, Höttecke and Allchin, (2020) argue more responsibility falls on the average citizen to distinguish reliable science from junk science, whereas historically, science journalists had a professional responsibility to ensure the accuracy of scientific information. However, Höttecke and Allchin, (2020) are clear to point out that cautionary disclaimers or diagnostic tools for evaluating sources are insufficient in developing the media literacy skills that science educators desire—"Rather, students need to understand, more holistically, the epistemic structure and provenance of scientific claims that they encounter in everyday life" (p. 646). Our study demonstrates that the science teacher participants do indeed use scientific media literacy to inform their thinking around socioscientific issues. However, the extent to which they help their students engage in such thinking is unknown. Given the observations made by Namdar et al., (2020) and this study, researchers and science educators may want to further consider the ways to help K-12 students engage with media literacy when considering SSI.

Role of Nature of Technology Views in SSI

Given the technological nature of many SSI, it is not surprising that individuals in our study drew heavily from NOT. In most cases, the science and technology related to an SSI are incredibly intertwined (Tala, 2009). Therefore, any discussion of SSI is likely incomplete without consideration of the NOT (Clough, 2013; Kruse, 2013a; Kruse et al., 2017; Kruse & Wilcox, 2013; Pleasants et al., 2019). As technology is the focal point of many SSI, perhaps "socio-technological issues" is a better label. For instance, the issue in this study, road salt, and another common SSI, genetic engineering, are primarily issues of technology. Thus, three key ideas emerge: (1) many SSIs are technological in nature, (2) NOT was prevalent in our participants' thinking, and (3) NOS played a limited role in both our study and a host of other studies (Bell & Lederman, 2003; Walker & Zeidler, 2003; Zeidler et al., 2002). Given these three ideas, perhaps understanding NOT is more important than understanding NOS when considering SSI.

Although participants in our study primarily drew on NOT rather than NOS, their use of the NOT was mostly limited to discussion of tradeoffs and limitations of technologies, such as the environmental effects of using road salt or the financial advantages of using road salt. Other aspects of the NOT that may be useful in consideration of an SSI, such as how technology impacts society and influences the way people think and act, were rarely addressed by participants. Perhaps participants in our study had weak understanding of these aspects of the NOT so more focus should be put on these aspects in science teacher education and K-12 science classrooms. It is also possible that participants in our study did have informed beliefs about other NOT aspects, but simply did not use them, similar to how participants in Bell and Lederman's (2003) study had informed NOS views but did not draw from those views to inform their thinking regarding SSI.

Given the relative dearth of NOT studies in the SSI literature, more work is clearly needed. Although some science educators have published strategies to include NOT in elementary (e.g., Holub et al., 2020; Kruse & Wilcox, 2017a; Wilcox et al., 2021), middle (e.g., Kruse & Wilcox, 2013; Rockefeller & Kruse, 2020; Voss et al., 2020), and high school classrooms (e.g., Kruse et al., 2017; Kruse & Wilcox, 2013; Kruse & Wilcox, 2017b), only a few studies in science education have collected evidence of K-12 student thinking and learning about NOT (e.g., DiGironimo, 2011; Kruse, 2013b). Thus, this study adds to the practical and emerging empirical NOT literature by illustrating the extent to which NOT-related thinking was used by our participants when thinking about an SSI. Given the emerging theoretical and conceptual work around NOT in science education (e.g., Olson & Clough, 2013; Herman, 2013; Kruse, 2013a; Pleasants et al., 2019; Waight & Abd-El-Khalick, 2012) and the results of this study, further work exploring the connection between SSI and NOT is warranted.

Limitations and the Potential for Framing Effects

A few limitations are inherent in this study. First, the small sample size of our study makes it likely that our results are not generalizable. The SSI we had participants read about is regional. Science teachers who are not from the Midwest may think differently about the road salt issue than our participants did.

A second limitation is the potential framing effects. Kahneman, (2002) described the framing effect: “Framing effects in decision making arise when different descriptions of the same problem highlight different aspects of the outcomes” (p. 456). Several studies have demonstrated that the way that an issue is framed can change individuals’ decision-making regarding the issue (Scheufele & Tewksbury, 2007; Shafir, 1993; Tversky & Kahneman, 1989). Furthermore, Topcu et al., (2010) found that individuals’ reasoning can be dependent on context, and therefore a different SSI may have led to different results. Considering the framing effect and the role that context can play in SSI, we suggest that the way an SSI is framed might contribute to the knowledge domains used. For instance, the article used in this study focuses heavily on the tradeoffs of using road salt as well as the pros and cons of alternative technologies, which may be why participants in our study drew so heavily from tradeoffs within NOT.

Conclusion

This study directs attention to the role that both NOT and media literacy can play in individuals’ thinking about SSI. Given the prevalence of NOT in our results, the inherent technological aspects of SSI, and the weak connection between NOS and SSI in the literature, it is possible that NOT may be more intuitive and useful to individuals than NOS when considering SSI. Additionally, we suggest that framing effects may play a large role in individuals’ thinking and decision-making regarding SSI. In terms of this study, the fact that participants read an online news article may have influenced them to draw on their knowledge of the media. However, information about many SSI is obtained at least in part from public media. Thus, media literacy may be a knowledge domain that individuals need to draw on regardless of SSI context. The prominence of both the NOT and media literacy in our participants’ thinking lead us to suggest that those knowledge domains be given additional attention in science classrooms if we are to develop scientifically literate citizens. Future research should expand on the role of the NOT and media literacy in SSI consideration, as well as the effect of SSI framing on individuals' reasoning and decision-making regarding SSI.

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Declarations

Conflict of Interest The authors declare no competing interests.

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