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Nuclear wastewater release to the Pacific Ocean: An environmentally critical socio-scientific issue to promote students' and teachers' grasp of evidence

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ABSTRACT

Socio-scientific issues (SSIs) can work as an effective mediator to promote secondary students and science teachers' environmental and science learning. This study explores one of such SSIs: The controversy over Fukushima's nuclear wastewater release (NWR) to the Pacific Ocean, characterized by expert disagreement on predicting associated environmental risks. Aimed at producing a theory informed articulation of the issue useful for instructional purposes, this study conducted a content analysis of NWR by employing the grasp of evidence (GOE) framework, particularly attending to risk-related statements extracted from publicly available digital news articles and supporting documents mostly produced over one week during the time the release plan was officialized. The GOE-informed analysis articulated the expert disagreement by identifying statements focused on managing, predicting, and communicating risks of radioactive wastewater release. The analysis revealed 41 knowledge claim codes derived from 263 statements. These claims addressed the trustworthiness of arguments for the released water's safety from the four evidence dimensions: analysis, evaluation, interpretation, and integration. Additionally, 10 claim codes emerged from 50 statements addressing the sociopolitical and ethical aspects of dealing with risks. Analysis of speakers of the knowledge claims revealed two contrasting positions on the NWR, release advocates or skeptics, as well as their professional status and potential interest relations. Findings demonstrate how GOE can facilitate science students' and teachers' socio-scientific reasoning by fostering multidimensionally evaluative approaches to competing knowledge claims and their speakers so as to promote socially and ethically conscious grasp of the controversy over NWR. Discussions consider the potential applications of NWR for the SSI-based interdisciplinary environmental and science instructions in science methods courses and secondary science classrooms.

Keywords: socio-scientific issue, socio-scientific reasoning, grasp of evidence, risk assessment, nuclear wastewater

INTRODUCTION

Socio-scientific issues (SSIs) refer to science-related matters of personal and societal significance (Zeidler et al., 2005). SSIs feature "complex, open-ended, often contentious dilemmas, with no definitive answers" (Sadler, 2004, p. 514). Studies on SSI-based science education have leveraged SSIs as a means of students' socio-scientific reasoning that involves evidentiary practices and multiple-perspective taking (Karisan et al., 2017; Kolstø, 2001; Sadler et al., 2007). By engaging in SSIs, students are expected to make better-informed decisions and conscientious actions that will have a great impact on both their lives and those of the local and global communities they care about (Zeidler et al., 2019).

Despite the potential benefits of SSI-based science education, research highlights the instructional challenges teachers face when integrating SSIs into their classroom instruction. These challenges range from facilitating balanced discussions without hindering students' exploration of diverse perspectives (Albe, 2008; Pedretti et al., 2008) to aligning SSIs with mandated curriculum standards (Pedretti et al., 2008; Sadler et al., 2006). The inherent complexity of SSIs, which involve multiple stakeholders, knowledge claims, and controversial decision options, can further compound these challenges (Kolstø, 2001). Some teachers may perceive themselves as lacking content familiarity, knowledge and strategies for dealing with complex and multifaceted SSIs, potentially limiting students' full engagement with the issues

(Bryce & Gray, 2004; Lee & Yang, 2019). Consequently, teachers may hesitate to cover SSIs in their science classrooms.

Responding to the reported challenges that should be addressed by SSI-based science education scholarship, this study attends to the importance of ongoing identification and elaboration of SSIs. Particularly, this study resonates the need for searching and developing new SSI topics to teach and learn to further advance the current SSI research and practices, as suggested by a recent systemic review on teaching SSIs (Högström et al., 2024). Providing teachers and teacher educators with systematically analyzed SSIs facilitate the application of the issues into instruction by enhancing familiarity with the content and context (Amirshokoohi et al., 2022; Topcu et al., 2010). Among the SSIs identified and utilized in prior work, examples include antibiotic resistance (Peel et al., 2019), embryonic stem cell research (Molinatti et al., 2010), and hydraulic fracturing (Romine et al., 2017).

In line with the need for identifying instructible SSIs, this study conducts a content analysis articulating one environmentally critical SSI: Fukushima's nuclear wastewater release (NWR) to the Pacific Ocean. This issue is characterized by expert disagreement and competing knowledge claims regarding the predicted environmental risks associated with the release. Particularly, this study seeks to articulate the NWR controversy by employing grasp of evidence (GOE) (Duncan et al., 2018) as a conceptual framework to inform a content analysis of publicly available digital resources. GOE encompasses two categories of evidentiary reasoning practices: laypersons' and experts' use of evidence. This study uses the evidentiary reasoning practices in GOE framework to analyze NWR in terms of competing claims and their speakers involved in NWR. Informed by GOE, two research questions (RQ) guide this study:

RQ1. What knowledge claims comprise the controversy over NWR?

RQ2. Who comprise the speakers of those knowledge claims? What are their positions and interest relations to NWR implementation?

Addressing these questions, the primary goal is to articulate the expert disagreement over NWR so that the findings can contribute to using NWR and GOE for SSI instruction and raising awareness on the NWR. Given the content knowledge related to NWR and its relevance to science standards (e.g., National Research Council, 2013), the findings are expected to be applicable to secondary science classrooms and science methods courses.

LITERATURE REVIEW

This section introduces NWR as the focal SSI of this study and reviews the literature on epistemic and social challenges in dealing with SSIs, particularly those involving potential risks. GOE (Duncan et al., 2018) is discussed as a conceptual framework for analyzing NWR as a risk-involved SSI.

Nuclear Wastewater Release to Pacific Ocean

On March 11, 2011, a magnitude 9 earthquake and tsunami struck northeast Japan, severely damaging the Fukushima nuclear plants' power supply. This stopped the cooling water system, causing reactors to overheat and melt down (Sugiman, 2014). Normally, cooling water circulates without contacting the reactors. However, the meltdown led to direct contact, making the water highly radioactive and contaminating both the entire facility and neighboring regions (Koo et al., 2014). Over a decade, the Japanese government explored various options to dispose of nuclear-contaminated wastewater, and finally chose to release the wastewater into the Pacific Ocean (Normile, 2021). The government argued that wastewater would undergo rigorous filtration to eliminate dissolved radioactive molecules (i.e., radionuclides). Tokyo Electric Power Company (TEPCO) took charge of devising a radioactivity-filtering facility called the advanced liquid processing system (ALPS). ALPS reportedly has the capacity to filter 62 out of 64 different kinds of radionuclides from the wastewater, decreasing the radioactivity level so that the water meets the international safety standard. On July 4, 2023, the International Atomic Energy Agency (IAEA, 2023) announced that their inspection confirmed ALPS had successfully reduced the radioactivity of nuclear wastewater. Immediately following this announcement, Japan publicly confirmed its plan to initiate the release. Accordingly, on August 24, 2023, more than 1 million metric tons of ALPS-treated water was released for the first time and is estimated to continue for three to four decades.

The release, however, proceeded without expert consensus on the prediction of the types, likelihood, and magnitude of risks to environment and human lives. Drawing on Gandolfi's (2024) notion that reconsiders nature of knowledge construction by disrupting and broadening epistemic authority (i.e., whose knowledge counts and matters), I consider that experts include not only those in related academic disciplines (e.g., nuclear scientists, marine biologists, environmental activists, and economists) and those who have experiential and contextual knowledge on the NWR (e.g., local community members, fishery industries, and government officials). While the Japanese government and IAEA claim the safety of ALPS and minimum risk of radiation exposure, there are independent experts who have expressed concerns about the unprecedented scale and duration of this release as factors that make risk prediction difficult (Nogrady, 2023). For citizens facing the issue, it can be challenging to determine whether this appearance of experts' disagreement is superficial or indicative of a substantial dispute. This situation contrasts with cases where scientific community consensus serves as a reliable reference for civic and policy decisions, as seen in the overall consensus on human-caused climate change (Lynas et al., 2021). Conversely, the appearance of experts' disagreement can overwhelm citizens when deciding which claims to trust and how to respond.

Challenges and Opportunities for Engaging in Risk-Involved SSIs Like NWR

For citizens "with a general education and not specialized knowledge of a field" (Chinn & Duncan, 2018, p. 96), engaging with controversial SSIs can pose epistemic and social challenges. Epistemic challenges pertain to competing knowledge claims entailed by SSIs. The claims draw on knowledge in the making through ongoing inquiries, and due

to the ongoing nature their trustworthiness is not always be assured (Kim & Alonzo, 2021; Kolstø, 2001). Epistemic challenges are greater when expert disagreement on SSIs is genuinely or apparently significant (Chinn et al., 2014). Moreover, the challenges are complicated by the inherent social nature of SSIs that involve various stakeholders with divergent interest relations, perspectives, and dynamics (Kahn & Zeidler, 2019). Stakeholders may selectively use or misuse knowledge claims to serve their interests or make the expert disagreement seem greater than it actually is, creating public controversy and confusion (Kolstø, 2001). Media also plays a complex role: not only educating citizens, but often intentionally or unintentionally spreading biases or oversimplifying complex issues (Sharon & Baram-Tsabari, 2020).

These epistemic and social challenges are amplified when SSIs present potential risks as exemplified by NWR. Risk is a common feature among many SSIs characterized by uncertain future consequences (Kolstø, 2006; Schenk et al., 2021). In general, risk is described as the potential for a particular situation (i.e., action, condition, or decision) to cause harm, encompassing the likelihood, magnitude, and duration of the harm (Field & Behrman, 2004; Fischhoff et al., 1984). In the case of NWR, risks are complex ranging from the risks of failure in running the ALPS system to those of adversely impacting human health, global economies, and marine environments. Moreover, the likelihood, magnitude, and duration of these risks have not yet reached consensus among experts. NWR is one of SSIs contemporary societies face the uncertainty in risk predictions as well as the ordeals of making risk-related decisions that can lead to significant consequences for health, environment, and international relations (Develaki, 2024).

Despite the significant challenges in dealing with SSIs marked by uncertain risks and expert disagreement on risk predictions, there is still merit in addressing the complexity. Chinn and Duncan (2018) posit that even when science cann*ot guarantee better judgments* on issues with expert disagreement, it can *still foster a better understanding* of such complex matters. Being able to better understand complex SSIs through the reasoning practice of and about science can be considered "an intrinsically valuable epistemic achievement in its own right" (p. 96). This notion of better understanding aligns with Feinstein's (2011) concept of competent outsiders to science, emphasizing citizens' agentic role in critically engaging with real-world tasks like SSIs.

About the concept of better understanding that can sound broad and abstract, the SSI education scholarship provides a construct, socio-scientific reasoning. Socio-scientific reasoning involves four aspects: recognizing the complexity of SSIs, understanding the tentativeness of knowledge claims involved in SSIs due to their reliance on ongoing scientific inquiries, exercising skepticism on the information and speakers, and taking multiple perspectives involved in the issues (Sadler et al., 2007). Advanced exercise of socio-scientific reasoning entails the balanced use of different modes of reasoning from rationalistic to emotive and intuitive (Sadler & Zeidler, 2005), enhancing the consideration of multiple perspectives (Zeidler et al., 2019). Socio-scientific reasoning of an SSI like NWR that features expert disagreement can start with navigating diverse claims made by multiple stakeholders, by maintaining a constructive skepticism to examine their trustworthiness, which will help to inform conscientious decisions and actions.

GOE as a Conceptual Framework of the Study

Given that disparate risk predictions are central to the controversy over NWR, socio-scientific reasoning on this issue necessarily involves risk analysis. Risk analysis encompasses ethical, moral, and sociopolitical deliberations (Hansen & Hammann, 2017), as well as examination of risk features (probability, magnitude, and duration), identification of subjects at risk, and discussion of risk management (Aven & van Kessenich, 2020; Society of Risk Analysis, 2018). Risk-related knowledge claims should be scrutinized for their epistemic aspects–that is, their trustworthiness in terms of how they were generated and reasoned from evidence, and whether this evidence was established through reliable processes.

To facilitate the examination of risk-related claims over NWR, this study adopts GOE proposed as a framework of evidentiary reasoning practices for students as "competent outsiders to science … while also benefiting those who will go on to become insiders to science, science communicators, or science educators" (Duncan et al., 2018, p. 911). Duncan, Chinn, and Barzilai (2018) view that citizens–including students–whose science knowledge is more general than specialized can still effectively engage in an epistemic approach to evaluate science-related reports by using GOE. GOE clarifies the aims, ideals, and reliable processes of multidimensional evidentiary practices in generating, evaluating, using, and communicating scientific knowledge claims. GOE entails two categories of evidence use

(1) experts' firsthand use of evidence–i.e., "how scientists use evidence" and

(2) laypeople's second-hand use of evidence–i.e., "how laypeople can reasonably use the evidence reported by scientists" (Duncan et al., 2018, p. 911).

First-hand use of evidence refers to the evidentiary reasoning dimensions citizens should understand about how scientists generate, justify, and critique evidence and knowledge claims. GOE framework outlines four interconnected evidentiary dimensions: evidence analysis, evaluation, interpretation, and integration (Duncan et al., 2018, pp. 915-916). *Evidence analysis* involves examining the components of empirical studies, including study design, data collection, and hypotheses (or models) tested as well as the coherence among these components. *Evidence evaluation* builds on analysis by critically examining evidence in consideration of factors that can determine its quality, reliability, and validity such as appropriateness of study design, data analytic methods, and source of errors. *Evidence interpretation* focuses on how evidence relates to theoretical models or claims, assessing the strength of evidence in supporting or refuting models, and understanding how models explain evidence. *Evidence integration* involves coordinating large, diverse bodies of evidence, often through systematic reviews or meta-analyses, weighing the quality and strength of different sources to support or refute theories. These dimensions are closely interrelated, with each building upon and informing the others to create a comprehensive approach to understanding scientific evidence.

In addition to expert use of evidence, Duncan et al (2018) articulate lay use of evidence as secondhand examination of scientific studies reported in public media platforms such as news articles. Citizens primarily access background knowledge, information, and diverse claims through these secondhand reports. Citizens can assess, for example, if the reports present competing claims in a balanced manner, if the media platforms are generally trustworthy, and if speakers seem to have any conflicts of interests. Citizens can also look up whether there is a consensus within the scientific community regarding the reported knowledge claims. When experts' consensus is unavailable like NWR, lay use of evidence may attend to social relations and contextual factors surrounding SSIs.

Clarifying the five dimensions through which evidence is established and communicated, GOE facilitates sophisticated engagement with firsthand and secondhand reports of evidence (Duncan et al., 2018). GOE's approach to developing competent outsiders to science is especially relevant to NWR, which seems to lack expert consensus but is abundant with competing claims. By applying GOE, this study seeks to parse out the claims and their speakers' positions so that this study's findings can contribute to using NWR for designing SSI-based instruction.

METHODS

To answer the two research questions, a content analysis was conducted on the statements extracted from publicly available digital resources covering NWR controversy. This approach allowed me first to extensively explore and select resources, and then employ GOE to articulate the NWR in terms of competing claims, and the speakers and contexts making the claims.

Positionality

In this study, I take a dual positionality. First, I position myself as a citizen reasoner with general rather than specialized knowledge on NWR. I acknowledge that my limited access to comprehensive knowledge may preclude a finite answer on whether or not to take a side for or against the NWR. Still, I strive for secondary use of evidence while emulating firsthand use of evidence, aligning with Duncan et al.'s (2018) and Feinstein's (2011) notion of competent outsiders to science. Second, I position myself as a teacher and teacher educator examining the utility of NWR and GOE for future SSI-based instructions. While the primary goal of the study is to articulate the NWR informed by the 'citizen' position, I maintain the second position to discuss whether this study can produce initial resources for SSI-based instruction. This dual positionality allows me to model the effort for better understanding, inspired by Chinn and Duncan (2018) encouraging the attempt at understanding as "an intrinsically valuable epistemic achievement in its own right" (p. 96).

Data Selection

Primary data sources are on publicly available digital contents, including news articles and non-news article documents mostly produced over one week during the time the release plan was officialized. Data selection focused on the ability of the selected resources to answer the RQs about articulating how the risk-related claims of NWR are justified in light of evidentiary dimensions (**RQ1**) and communicated in public forums (**RQ2**). Selection criteria were established and applied for search keywords, search time frame, and the forms and content of the resources. **Table 1** shows the specifics and reasoning of the criteria employed.

Table 1. Criteria for data selection

CADS	Criteria

Search keywords	• Using Google's online search system.
	• Including keywords that indicate the following:
	  ○ **Area information** (e.g., Japan or Fukushima),
	  ○ **Water descriptors** (e.g., nuclear, wastewater, contaminated, radioactive, and treated), disposal-plan descriptors (e.g., release, ALPS, filtered, and to ocean).
	  ○ Some of these **keywords combined** (e.g., 'Japan Fukushima nuclear wastewater release to the ocean,' 'Fukushima nuclear contaminated water,' and 'Japan ALPS filtered water')

Search time frame	• Main resources: News articles published **between July 4 and July 11, 2023:**
	  ○ Because the IAEA endorsed the ALPS water filtering system on July 4, and Japan reconfirmed its water release plan. Since the announcement, the news media increased its coverage of this issue, which had suddenly transformed from a distant prospect to an imminent reality).
	• Resources published **since April 2021** (when Japan first announced its discharge plan) and **before July 4, 2023:**
	  ○ If they provided contextual information regarding how the NWD plan was first announced and discussed.
	• Resources published on **August 24, 2023** (the date Japan started the water discharge) and **afterward:**
	  ○ If they presented new details about the implementation of the discharge plan in ways that complemented the content of the resources already collected.

Resource format and content	• **News articles publicly available online** were selected as primary data
	  ○ When they delivered comments from experts or representative stakeholders, presenting both sides (for and against) of the issue, rather than just one side. I set this criterion in hopes of ensuring balanced access to competing claims.
	• **Non-news documents publicly available online** were added
	  ○ When they provided a rich set of claims, perspectives, reasonings, or information crucial to understanding competing claims about the NWD produced by the major stakeholders (e.g., the IAEA, Japan's Ministry of the Environment, Greenpeace, or the Pacific Island Forum).

Other format consideration	• Linguistic mode: resources written in English, or **available in English** were selected so as to see the coverage of the NWD controversy aimed at a global audience • Source identity: resources are selected if the authors and their affiliated media outlet were clearly identified

Note. CADS: Considered areas for data selection

Table 2. Summary of data selection

	Details of the selected resources (total N = 52 articles)

News articles	• Number of resources: 41
	  ○ 27 (published between July 4 and July 11, 2023, per Japan's reconfirmation of its water discharge plan)
	  ○ 6 (published since April 2021, when the discharge plan was first officialized, and before July 4, 2023)
	  ○ 8 (published on or during the week after August 24, 2023, when Japan started to discharge the water)
	• Number of resource outlets: 29
	• Addressed both advocate and skeptic sides of NWD controversy

Non-news article documents	• Number of resources: 11 • Number of resource outlets: 8 • Presented one of the two sides, release advocate (6) or skeptic (5)

Data selection continued until the newly searched resources contained content already appearing in previously collected resources. This process resulted in 52 publicly available digital resources (41 news articles and 11 non-news digital resources) generated from a total of 37 outlets (**Table 2**). The number of resources and outlets differed because some outlets produced multiple resources.

The selected data are organized into an electronic spreadsheet. In this electronic spreadsheet, hyperlinks were pasted to the original sources and input their contextual information by adding columns for the resource titles, dates of publication, authors (reporters), and resource outlets.

Data Analysis

The data analysis proceeded in three phases. In the first phase, idea unit statements were extracted from the selected digital resources into a data table, guided by literature on risk analysis and multidimensional reasoning of SSIs. I extracted statements when they attended to the matter of risks involved in NWR, including risk management, risk predictions, or risk communication. In particular, these statements were related to the claim that ALPS (the radionuclides filtering facility) was inspected and proven to be safe, posing minimum to no risks. These extracted statements ranged from short phrases to multi-sentence comments, encompassing claims, evidence, or reasoning related to NWR and its risks. The data table was augmented with columns specifying speakers (including individual experts, organizations, and communities) and their positions on NWR. This process resulted in the extraction of 313 statements from 42 speakers.

In the second phase, I analyzed the idea unit statements according to the GOE framework that entails lay and experts' use of evidence (Duncan et al., 2018). First, the extracted statements were coded in light of the experts' four evidence dimensions (**RQ1**). To ensure coding reliability, this analysis involved three independent coders including the author, and calculated intercoder reliability (Shea, 2015). Two graduate research assistants participated in the coding. At the time of coding, they had taken my course where I introduced GOE with a reading and course activity. I also held a training session where the GOE and initial coding scheme was introduced. We then independently coded a randomly selected 25% sample of the statements (78 out of 313) on the electronic spreadsheet. Intercoder reliability was calculated as Kappa values, respectively of 0.89 and 0.91, indicating substantial agreement (Gwet, 2014). The remaining statements were independently coded. When we had statements coded differently, we discussed them until we reached consensus as we refined the coding scheme concurrently (**Table 3**). As a result, among a total 313 extracted statements from 42 speakers, 263 ones from 37 speakers fell under the respective evidence dimensions (63 statements for evidence analysis, 55 for evaluation, 61 for interpretation, and 84 for integration). In addition to the four evidence-based codes, a fifth code, sociopolitical dimension, was created to categorize the remaining 50 statements from 5 speakers. This emergent coding reflects the literature emphasis on SSIs featuring multiple perspectives (Zeidler et al., 2019). These statements addressed aspects beyond evidence-based reports, focusing on the appropriateness of the decision-making process, and ethics and justice concerns.

To address **RQ2**, I applied the lay use of evidence framework to analyze speakers' positions, status, and interest relations. While lay use of evidence typically encompasses a broader contextual consideration, including checking for expert consensus and examining media platform trustworthiness (Duncan et al., 2018), expert consensus was not apparent in NWR, and media platform trustworthiness was already addressed through the study's data selection process. Moreover, in the NWR debate, some speakers' positions were closely tied to their professional status. Given these factors, I focused primarily on 37 speakers who made statements assigned to the evidence dimensions. Reading and categorizing statements by the speakers' views on NWR, distinct positions were identified: release advocates (15 speakers) and release skeptics (22 speakers). Their professions were then coded into four groups: scientists, international organizations, national representatives (whether the government or the citizens), and industries. Their interest relations regarding NWR implementation were also considered, based on publicly available online information about their affiliations, professional experiences, and projects involved. Accordingly, speakers were categorized into one of three interest relations: those whose interests align with NWR implementation, those who oppose it, and those whose interests are unclear. Here, 'unclear' label indicates that accessible information didn't reveal sufficient evidence to determine the speakers' interest relations regarding NWR implementation. The results of this analysis are tabulated and elaborated in the Findings.

In the third phase, the statements assigned to the four evidence dimensions were subsequently coded to articulate claims constituting respective evidence dimensions (**RQ2**). Subsequent coding was also conducted on the statements assigned to the sociopolitical dimension, the newly emerged category. This time, I first conducted an initial grouping of randomly selected 25% of statements from each dimension. I shared the initial grouping results with two coders, and we

Table 3. Final coding scheme: Evidence dimensions (Duncan et al., 2018) and socio-political dimension (emerged from data)

	Coding logic	Examples of statements coded
Evidence dimensions		
Evidence analysis	Code a statement as evidence analysis when the statement addresses components of the ALPS performance inspection process for filtering radionuclides from wastewater, or the coherence between the inspection design and the safety claims being tested.	Statement focuses on or is relevant to: · methods used for wastewater sampling, · adequacy of wastewater sample size in representing the original wastewater composition, · methods used to measure and analyze radionuclide types and amounts before and after ALPS filtration, · transparency in reporting the whole process of ALPS performance inspection to independent experts, · transparency in reporting filtration results to independent experts and subjecting them to peer review, · ALPS filtering mechanisms
Evidence evaluation	Code a statement as evidence evaluation when the statement addresses the quality, reliability, and validity of the ALPS inspection results comparing pre- and post-filtration radionuclide levels, considering alternative explanations for these results.	Statement focuses on or is relevant to: · reliability of measurement tools in detecting concerning radionuclides, · specific types of radionuclides successfully filtered by ALPS, · presence of any high-risk radionuclides remaining after filtration, · proportion of residual radionuclides post-filtration · magnitude of change in radiation levels before and after ALPS filtration
Evidence interpretation	Code a statement as evidence interpretation when the statement addresses the strength of the ALPS inspection results in supporting safety claims, in relation to international safety standards or theories of radiation risks.	Statement focuses on or is relevant to: · strength of inspection results supporting the claimed safety, · validity of the claimed minimal to non-existent risk in relation to international safety standards, · accuracy of the predicted minimal to non-existent risk when considered against theories of radiation impacts on human health and marine ecosystems, · assessment of uncertainty in risk prediction, given the unprecedented duration of the planned release
Evidence integration	Code a statement as evidence analysis when the statement examines waste disposal research and practices, including radiological literature, existing disposal methods, and alternative options proposed for Fukushima wastewater disposal.	Statement focuses on or is relevant to: · consideration of post-filtration radioactivity levels in the context of studies on long-term, low-dose radiation exposure effects. · comparison between ALPS and existing nuclear wastewater disposal strategies. · comparison of the safety level between ALPS and alternative proposed methods for Fukushima wastewater disposal.
Code emerged from data		
Socio-political dimension	Code a statement as sociopolitical when the statement addresses social, procedural, and ethical aspects, beyond justifying or critiquing knowledge claims.	Statement focuses on or is relevant to: · appropriateness & fairness in decision making · responsibility and eligibility of ALPS management · view on NWR in terms of ethics, justice, responsibility

discussed the appropriateness of grouping of statements and assigned a sentence-format code to each group. I then conducted an inter-coder reliability test on another random 25 % of statements from each dimension. The intercoder reliability test resulted in the Kappa values of 0.87 and 0.90, indicating substantial agreement (Gwet, 2014). As we coded the remaining statements, we discussed any discrepancies in our coding and refined the claim codes until consensus was reached. As a result, 263 statements in the evidence dimensions resulted in 41 sentence-format codes that present risk related knowledge claims (e.g., 'The amount of tritium is too small to ingest and bioaccumulate'). Statements were grouped into 7 codes (4 advocates and 3 skeptics) for evidence analysis; 12 (6 and 6) for evidence evaluation; 11 (4 and 7) for evidence interpretation, and 11 (4 and 7) for evidence integration. 50 statements in the sociopolitical dimension were grouped into 10 codes (5 advocates and 5 skeptics).

Limitations

I acknowledge several limitations of this study. Regarding data selection, while I positioned myself as a citizen relying on publicly available digital resources to understand NWR, this approach may not capture the full spectrum of expert opinions and evidence. As a researcher outside Japan, access to resources in Japanese was limited. Despite efforts to achieve sufficient richness and variety, the selection of digital resources may have inadvertently excluded certain viewpoints or information sources, particularly those from local communities not captured by the resources I selected. In terms of data analysis, although I employed coding with two coders and measured intercoder reliability to mitigate potential bias, the final refinement of codes was conducted amongst us, which may introduce some level of subjectivity in interpretation and categorization. Furthermore, this study utilized GOE to articulate specific features of expert disagreement in NWR. As such, employing other frameworks for analysis can lead to different interpretations.

FINDINGS

Drawing on the three-phase content analysis of digital resources, this section first articulates the competing claims that comprised the NWR controversy, and then describe the

Table 4. Number of claim codes in each dimension (see **Appendix A** for the full list of claim codes)

	Release advocate (total N = 18)	Release skeptic (total N = 23)
Evidence dimensions (Duncan et al., 2018)		
Evidence analysis	4	3
Evidence evaluation	6	6
Evidence interpretation	4	7
Evidence integration	4	7
Socio-political dimension		
Socio-political	5	5

speakers who made claims addressing evidence dimensions, focusing on their positions and their contexts.

RQ1. What Knowledge Claims Comprise the Controversy Over NWR?

As a result of the data analysis phase 1, I extracted statements that addressed the matter of risks. Some statements justified or critiqued the claimed safety of wastewater release. Some statements predicted the likelihood and magnitude of the water disposal's impact on human and environmental health. Still other statements attended to the policy and process of the Japanese government's decision making on how to dispose of the Fukushima radioactive wastes. By referring to the coding scheme developed based on the GOE's experts' firsthand evidentiary reasoning (see **Table 3**), I coded with two additional coders the 263 statements into four evidence dimensions and subsequently coded them into 41 knowledge claims. Also, drawing on the statements that discussed risk beyond evidence dimension, 50 statements were coded into 10 sociopolitical claims. **Table 4** shows the numeric comparison of the codes in each dimension. See **Appendix A** for the full claims.

Even though the numeric comparison does not warrant statistical significance, it provides a snapshot of competing claims at each dimension. In what follows, I unpack the competing claims in the format of a dialogue between two imaginary individuals: Adrel (**Ad**vocate for **rel**ease plan) and Skerel (**Ske**ptic of **rel**ease plan). This personalization does *not* mean that every individual speaker in the same position shares the same view. By acknowledging this drawback, however, I present the findings this way for two purposes. I seek to focus on illustrating the varying claims in a coherent manner, instead of calling out specific individuals' names presented in the original resources. And I hope the dialogic formats facilitate the instructional use of GOE and NWR. This format, for example, can afford a role play as a mode of understanding the focal SSI, or as the materials that can facilitate students' debates based on the dialogic depiction of controversy. Role play and debate have been crucial instructional approaches to SSI (Högström et al., 2024) as demonstrated by prior studies, for example, to address animal experimentations (Agell et al., 2015; Vicente et al., 2024).

Before elaborating the NWR controversy in terms of expert disagreement at evidence dimensions, I begin with illustrating the controversy at the sociopolitical dimension, by performing a dialogue between Adrel and Skerel. All the dialogue contents reflect the codes drawn from content analysis:

> **Adrel**: Water release is the most realistic solution to free up the space occupied by nuclear waste. It is not different from the historically done hazard disposal.
>
> **Skerel:** Historical precedent isn't a reason. Let's not repeat the unethical throwaway.
>
> **Adrel:** It is not a throwaway but will be well-managed by IAEA and TEPCO.
>
> **Skerel:** But TEPCO isn't qualified to operate ALPS. It is a company that caused the 2011 meltdown. It is concerning because NWR is an unprecedentedly long term plan.
>
> **Adrel:** Don't worry, the Japanese government will communicate throughout. It promised to support Japanese fishermen's recovery from recession that can temporarily occur due to people's fear of eating seafood.
>
> **Skerel:** This isn't merely about fear. It's an ethical issue for both humans and the environment. Pacific communities' historical suffering from radiation should stop.
>
> **Adrel:** That's an exaggeration. Some countries might oppose the NWR in order to take advantage of this situation, but this is not a diplomatic game. Let Japan release the water.

As illustrated by this dialogue, NWR involves diverse stakeholders with varying interests and unequal access to decision-making processes, including the Japanese government, TEPCO, IAEA, the Pacific Ocean-dependent communities, Japanese fisheries, and the ocean itself. While advocates argued for the necessity and safety of the release plan, skeptics viewed it as an ethical transgression. While skeptics questioned the credibility of TEPCO, advocates endorse it. While advocates treat the skeptics' concerns as merely emotional, skeptics validate the concern as a call for respecting human and marine lives relying on the Pacific Ocean's health and preventing further harm to the ocean. This complexity highlights multifaceted challenges such as procedural, social, emotional, and ethical.

Furthermore, these multidimensional challenges get complicated by the epistemic challenges posed by expert disagreement on the safety of ALPS-mediated wastewater release. In this complexity of NWR, examining experts' competing knowledge claims is not just technically evaluating the claims' trustworthiness, but is a helpful guidance in taking

socially and ethically conscientious grasp of the issue informed by evidentiary reasoning. What follows demonstrate such a multidimensional evidentiary reasoning that can assist a better understanding of the sociopolitical and ethical controversy over NWR.

NWR controversy at the evidence analysis dimension

Evidence analysis involves understanding both the components of scientific studies (e.g., hypothesis or model, methods, results) and the way these components coherently interrelate to one another to achieve the goals of the study. In the case of NWR, statements were coded as evidence analysis when they address the components of the ALPS performance inspection process for filtering radionuclides from wastewater, or the coherence between the inspection design and the safety claims being tested. 9 claim codes (6 advocates and 3 skeptics) were identified from 63 statements assigned to the evidence analysis dimension, drawing on the content analysis informed by the GOE's evidence dimension coding scheme. I illustrate the expert disagreement at this dimension by using the imaginary dialogue between Adrel and Skerel:

> **Skerel:** How was the water sampled and pre- and post-tested? The process should be transparently reported.
>
> **Adrel:** TEPCO, the experienced company that makes and runs ALPS, has already fully disclosed the ALPS procedure and monitoring plan. The inspection of the ALPS system was replicated by multiple labs located across the world. Furthermore, to ensure rigorous inspection, the IAEA made an impartial and scientific review.
>
> **Skerel:** They should disclose not only their plans but also the means by which they tested the reduction of radioactivity. How did TEPCO and the lab test ALPS?

As illustrated by this discussion between Adrel and Skerel on the evidence analysis dimension, speakers at both positions attended ALPS testing and operation procedures, including measurement, sampling, replicability, and procedural transparency. While advocates claimed the process of testing, operating, and monitoring ALPS would ensure the wastewater radioactivity reduction, skeptics critiqued this claim as lacking transparency in the report of measurements and sampling methods. While advocates highlighted TEPCO and IAEA as trusted leaders in inspection of ALPS's filtration capacity, skeptics called for the full disclosure of the process of testing ALPS.

NWR controversy at the evidence evaluation dimension

Evidence evaluation involves assessing the quality of evidence to determine how well the evidence supports the tested hypotheses or models. In the case of NWR, statements were coded as evidence evaluation when they address the quality, reliability, and validity of the ALPS inspection results comparing pre- and post-filtration radionuclide levels, considering alternative explanations for these results. 10 claim codes (4 advocates and 6 skeptics) were identified from 55 statements assigned to the evidence evaluation dimension, drawing on the content analysis informed by the GOE's evidence dimension coding scheme. I illustrate the expert disagreement at this dimension by using the imaginary dialogue between Adrel and Skerel:

> **Adrel:** ALPS filtered 62 out of 64 radionuclides in the Fukushima nuclear-contaminated water! Only tritium and carbon-14 remain after filtration. Tritium can't be filtered because it is part of discharged water molecule, but the amount of tritium in the treated water is very small.
>
> **Skerel:** Your claim can't be validated enough because the inspection result details are unavailable to the broader scientific community. While independent researchers have volunteered to perform peer reviews, TEPCO has rejected these offers. And, as even TEPCO acknowledged previously, the Fukushima water contains radionuclides other than tritium and carbon-14. Why aren't the other radionuclides reported in detail?
>
> **Adrel:** TEPCO did not reject scientific communities' offer to peer review. It just endorses the most renowned scholars in the field, brought by IAEA, to conduct the rigorous inspection of ALPS performance.
>
> **Skerel:** However, you should know that IAEA is not a scientific organization. That is an agency to promote nuclear power business. I am not sure if the scientists can be independent from the IAEA.

As illustrated by this dialogue, statements at the evidence evaluation dimension attended to the types of filtered radionuclides, available data, peer review processes, and alternative explanations for ALPS testing results. Advocates claimed that the evidence supporting ALPS treatment safety is of high quality, citing the high ratio of filtered radionuclides (62 out of 64) and the minimal remaining radioactivity in treated water. Conversely, skeptics challenged the credibility of these claims by highlighting a lack of transparency in reporting the results, particularly TEPCO's refusal of peer reviews. They also proposed alternative explanations for the alleged safety, suggesting the possibility of unreported radionuclides in the treated water. Skeptics questioned whether the evidence showing the reduction in radioactivity might be based on measurements of specific radionuclides while overlooking others. Advocates and skeptics showed contrasting views on who conducted the inspection and whether they are trustworthy, as a factor that would contribute to the evaluation of evidence's quality.

NWR controversy at the evidence interpretation dimension

Evidence interpretation involves examining the strength of evidence in explaining one or more models, theories, or hypotheses under consideration. In the case of NWR, statements were coded as evidence interpretation when they address how strongly the ALPS inspection results supported safety claims, in relation to international safety standards or theories of radiation risks. 11 claim codes (4 advocates and 7 skeptics) were identified from 61 statements assigned to the evidence interpretation dimension, drawing on the content analysis informed by the GOE's evidence dimension coding

scheme. I illustrate the expert disagreement at this dimension by using the imaginary dialogue between Adrel and Skerel:

> **Adrel:** The radioactivity level in ALPS-treated water falls below the most rigorous international standards.
>
> **Skerel:** Standards don't guarantee safety. Various national and international standards exist. They are set up by considering multiple factors, not only scientific but also diplomatic and political.
>
> **Adrel:** Regardless of the standards, the quantity of tritium in the treated water is too small. Although some studies say that tritium, when ingested, does bioaccumulate and increase the risk of cancer risks, the amount of tritium in the ALPS-treated water is too small to ingest and bioaccumulate. And studies show that minimal radiation exposure is natural and normal.
>
> **Skerel:** Did these studies consider long-term effects? Because the long term release planned like NWR is unprecedented, studies on long-term release like three to four decades are lacking. With tritium's 12.3-year half-life, we're uncertain how ocean-released tritium might bioaccumulate in the marine food web and ultimately affect humans. And what about other radionuclides claimed to be completely filtered by ALPS, given that even trace amounts of some are known to be highly detrimental?

As illustrated by this debate between Adrel and Skerel, speakers considered if the evidence (changes in the radioactivity of the ALPS-treated water) explains the hypothesis (When compared to other disposal methods, ALPS is safer to dispose of the wastewater) in light of the accepted knowledge on radiation risks and international safety standards. Advocates argued that ALPS-treated water meets international standards, claiming minimal risks based on studies showing limited causal links between radionuclides and health impacts. Skeptics, however, contended that these standards are influenced by political and diplomatic factors, not just science. They referenced research predicting significant adverse health and environmental effects, emphasizing uncertainties surrounding the risks of long-term, low-dose radioactive releases.

NWR controversy at the evidence integration dimension

Evidence integration addresses how evidence fits together with a larger body of literature in the field. In the case of the NWR, statements were coded with evidence integration when they situated the NWR in the context of waste disposal research and practices, including existing disposal methods, and alternative options proposed for Fukushima wastewater disposal. 11 claim codes (4 advocates and 7 skeptics) were identified from 84 statements assigned to the evidence integration dimension, drawing on the content analysis informed by the GOE's evidence dimension coding scheme. I illustrate the expert disagreement at this dimension by using the imaginary dialogue between Adrel and Skerel:

> **Adrel:** The methods used in ALPS are not new. They are similar to those widely used in ocean disposals at regular nuclear power plants. Other countries with nuclear power plants have also produced and released nuclear wastewater into the ocean.
>
> **Skerel:** However, Fukushima's nuclear-contaminated water differs from the water produced by typical nuclear power plants. At Fukushima, the water was directly exposed to and significantly contaminated by radionuclides, unlike the regular waste disposal at other nuclear plants.
>
> **Adrel:** But for the Japanese government needing to free up the on-land space and secure safety, release to the Ocean is the most realistic option. And it is safer than alternatives that could pose even greater health and environmental risks.
>
> **Skerel:** How so? I know there were about 5 options or so considered for the Fukushima wastewater disposal. Were the alternatives fully considered? For instance, after Chernobyl, the disposal method involved solidifying the waste, which is believed to be less detrimental than releasing it into the ocean, where radionuclides can easily spread. So why not solidification? Or, If the ALPS-treated water is so safe and radiation-free, why not reuse it for Japan's domestic water needs?

As this dialogue illustrates, the discussion in the evidence integration dimension includes two explicit themes. One theme was about the validity of ALPS as a disposal method in light of past disposal practices. Advocates defended NWR as similar to the pre-existing practices of ocean disposal normally done by nuclear power plants. However, skeptics problematized this assumption that the degree of radioactive contamination will be the same between the water from a regularly functioning nuclear power plant and the water from a nuclear meltdown, because the former did not contact the nuclear core while the Fukushima water radioactivity resulted from the water's massive direct contact with the nuclear core and following contamination. The other theme is the consideration of other disposal options. While advocates defended the ocean release, claiming that alternative disposal methods can pose higher risks than NWR, skeptics called for more consideration of alternative disposal options. As an alternative to NWR, skeptics suggested solidification or the domestic use of treated water as they can limit the spread of radioactivity when compared to the wastewater's release to the Pacific ocean.

RQ2. Who Comprise the Speakers of Those Knowledge Claims? What Are Their Positions and Interest Relations to NWR Implementation?

Even though I used the imaginary dialogue between Adrel and Skerel to illustrate competing claims of NWR, it was not that they represent only two persons, nor that the people sharing the same position on the NWR hold the same reasoning for why they took the positions. Speakers take different social or professional status, and their interest relations are complex. Lay use of evidence (Duncan et al., 2018) provides guidance looking at the context surrounding

Table 5. Speaker professions and their positions on NWR

Speaker profession and status	Release advocate	Release skeptic
National representatives (N = 11)	9 ([a]Japanese government officials)	2 ([b]1 China government speaker & [b]1 Korean citizen representative)
Company (N = 5)	1 ([a]TEPCO representative)	4 ([b]3 Japanese Fishery & [b]1 Korean Fishery)
International organizations (N = 3)	1 ([c]IAEA)	2 ([b]1 PIF* representative & [c]1 Greenpeace representative)
Scientists (N = 18)	[c]4	[c] 14
Total (N = 37)	**15**	**22**

Note. [a]Interests aligned with the NWR implementation; [b]Interests opposing the NWR implementation; [c]Unclear interest relations to the NWR implementation; PIF: Pacific Island Forum; *PIF is an international organization comprising 16 countries in the Pacific Region (PIF aims to secure their countries' political and economic success, and environmental safety protected from ocean contamination)

scientific reports, including speakers and their trustworthiness. Employing the lay use of evidence in consideration of speakers of knowledge claims, I identified 37 individual and organizational representative speakers grouped into four categories: scientists, international organization representatives, national representatives, or company representatives. Their positions on NWR were divided into advocate (15 speakers) or skeptic (22 speakers) (**Table 5**). The advocates --as performed by Adrel in the imaginary dialogues above-- presented a positive outlook on ALPS's ability to reduce the radioactivity from the wastewater to be released and predicted that the risk of dangerous water release is miniscule. In contrast, the skeptics --as performed by Skerel in the imaginary dialogues above-- presented critiques, concerns, and hesitance about the proclaimed NWR plan and predicted significant and long-lasting health, environmental, and economic risks.

The speakers' positions on NWR were further analyzed in terms of their potential interest relations, categorizing them based on whether their interests aligned with, opposed, or were unclear regarding NWR implementation. The majority of release advocates (10 out of 15, 66.7%) comprised 9 Japanese government officials and 1 TEPCO company representative whose interests explicitly align with the successful execution of the release plan. They uniformly claimed the safety of ALPS-mediated NWR and predicted minimal to no risks. Their statements reveal a determination to free up space in the Fukushima area while reducing the on-land nuclear contamination by disposing of nuclear waste into the ocean. The remaining 5 advocates, comprising 4 scientists and 1 IAEA representative, did not exhibit specific interest relations either favoring or opposing NWR implementation.

In contrast, the majority of skeptics (15 out of 22, 68.2%) comprised 14 scientists and 1 Greenpeace representative, whose interest relations to the NWR implementation appeared unclear, based on the information available online. This means that the majority skeptics did not demonstrate explicit interests opposing NWR implementation. The remaining 7 skeptics, however, comprise speakers with interests against NWR implementation: 1 Pacific Island Forum representative, 1 China government speaker, 1 Korean's citizen representative, 3 Japanese fishermen, 1 Korean fisherman. These stakeholders not only questioned the credibility of NWR advocates' safety claims but also criticized the lack of communication with communities whose livelihoods depend on healthy marine ecosystems.

This difference in interest relations across speakers, while not definitively determining the credibility of their statements, nevertheless provides one reference point to weigh their claims, given that interest relations can affect speakers' positions and aspects they choose to validate. Notably, scientists' interest relations appeared unclear, or likely remain neutral in both positions (4 scientists advocate, 14 scientists skeptical), based on the publicly available information on their affiliation and research experiences. Even without apparent vested interests, scientists presented competing knowledge claims. This apparent look of disagreement suggests the need for more deliberation to address their disparate claims on risk predictions.

Here, I also acknowledge that I put the two international organizations–the IAEA, which supports the NWR plan, and Greenpeace, a skeptic of the plan–into the 'unclear interest relation' category. From the publicly available information, it was uncertain what these two organizations might gain or lose from NWR implementation. However, I also admit that these organizations might have significant, undisclosed interest relations. The IAEA, aiming to promote nuclear energy use and having strongly supported Japan's NWR plan since its announcement, might have some undisclosed interests upon the implementation of the NWR plan. Conversely, Greenpeace, committed to environmental protection, may oppose the plan due to potential ocean contamination risks. These possibilities highlight the complexity of determining interest relations when seeking to practice lay use of evidence as secondhand evidentiary reasoning.

DISCUSSION

This study aimed to articulate the NWR controversy, characterized by expert disagreement on risk predictions, using the GOE framework as a conceptual guide. Particularly, I consider this study presents one example response to the call for developing and searching new SSI topics, as emphasized by Högström et al.'s (2024) systemic review of SSI teaching research. This study articulated NWR as a risk involving SSI as a new topic suitable to be explored in secondary science classrooms or science teacher methods courses, by facilitating GOE-informed evidentiary reasoning to help gain socially and ethically conscious grasp of the controversial SSI.

In this section, I review the findings of expert disagreement over NWR, extending the discussion to areas of agreement and areas that warrant further exploration. I then examine the utility of GOE in the context of SSI education literature, focusing on socio-scientific reasoning and risk analysis literature. Next, I discuss the potential applications of the overall findings for SSI-based instruction. Finally, I revisit the

study's limitations, highlighting critical areas for future research.

NWR as a Socio-Scientific Issue

This study begins with the challenge in discerning if the expert disagreement on the safety of NWR was actually significant or it was just a 'look' not that significant, specifically during the particular one week surrounding the IAEA's report on their ALPS inspection result that justified the Japanese government's release plan.

The content analysis of this study, however, hasn't yet reached the hard cut judgment on the significance of expert disagreement, which can be described as an epistemic challenge in engaging with real-world tasks like SSIs (Chinn et al., 2014). On the one hand, the findings reveal details that suggest the actual significance of expert disagreement across all evidence dimensions regarding the claimed safety of releasing the ALPS-treated nuclear wastewater. On the other hand, the significance of expert disagreement cannot be still concluded as there are remaining questions for citizens like me who have limited access to knowledge and information. For example, advocates say the IAEA's ALPS inspection is trustworthy as it was conducted and peer-reviewed by the most renowned scientists affiliated with IAEA, but skeptics question the IAEA's independence by pointing out the purpose of IAEA as an agency aimed to promote nuclear power business. From my search on the available resources, I wasn't able to have a valid ground to judge the independence of IAEA particularly in the NWR context.

Nevertheless, the findings provide a detailed map of expert disagreement in the NWR controversy, categorized by evidence dimensions, speaker characteristics, and associated sociopolitical issues. This elaboration reminds us of the merit of navigating expert disagreement to gain a deeper understanding of complex issues, as advocated by Chinn and Duncan (2018). Particularly, the findings afford a better understanding not only by sophisticating the expert disagreement through the GOE informed analysis but also informing the areas of agreement as well as the areas to be further explored.

From these findings, we can identify areas of agreement shared among release advocates and skeptics, from which their position to NWR diverged. Both sides acknowledged the presence of health, environmental, and economic risks posed by nuclear wastewater disposal and agreed that these risks should be mitigated. Among multiple options to tackle the risks, however, they were divided on the choice of the water release option. While they both acknowledged that releasing cooling water from typical nuclear power plants is a normal practice, they diverged on whether the ALPS-treated water's radioactivity level is comparable to that of typical nuclear power plant cooling water. While they agreed the existence of a varying kind and a massive number of radionuclides in the Fukushima wastewater, they diverged in whether to trust the claimed ALPS's filtration capacity. Regarding tritium, for example, both sides referenced accepted knowledge about its radioactive behavior, but their level of concern differed according to their prediction of the risks posed from the tritium's long-term low-dose release. In short, despite their baseline agreement, two sides reached a contrasting conclusion: one advocating for the ocean release while the other calling for a pause to take more time to consider alternatives and gather input from affected communities.

Another area of better understanding gained was what we do not know yet, and thus should know more based on the identified areas of disagreement and agreement. Even if we cannot secure answers to these newly emerged questions from the public forums, we still gained them as the momentum for further research or for the communication with experts. For example, the disagreement over the IAEA's trustworthiness begs questions about the agency's independence and credibility in inspecting and monitoring ALPS. We might ask: Who can assess the agency's independence and the objectivity of its affiliated scientists? Furthermore, given that the resources analyzed in this study mainly cited formal experts from scientists to international and national representatives, questions can also seek for the experiences and opinions of the very firsthand stakeholders actually impacted by the NWR. We can ask: where can we find the report of their voices? And how did the decision making process involve their voices? Questions also arose about the alternative wastewater disposal methods. Analyzed resources mentioned alternatives multiple times, but didn't detail them. What are the alternatives? What are the pros and cons? What is the Japanese government's rationale behind selecting the ocean-release option, beyond space shortage? Finally, as suggested by a skeptical scientist, the option of reusing ALPS-treated water for Japan's domestic needs warrants exploration. How was this option being discussed, and what are its implications? If the ALPS-treated water is indeed as safe as claimed, why not repurpose it for domestic use in Japan, rather than causing global concern through ocean release?

GOE-Informed Articulation of Risk-Involved Issues Like NWR

The areas of disagreement, agreement, and uncertainty discussed above indicate risk identification and prediction as key factors characterizing the challenges in engaging controversy over SSIs, which aligns with literature advocating for risk-conscious SSI education (Kolstø, 2006; Schenk et al, 2021). Despite the challenges, however, findings demonstrate an opportunity to gain a better understanding by utilizing GOE as a guide to parse out the controversy, particularly as a guide for using evidentiary reasonings to advance socially and ethically conscious grasp of the NWR as a risk-involving SSI.

The findings demonstrate how citizens can evaluate secondhand reports of risk considerations by emulating firsthand analysis of risk predictions and management. This approach contributes to the literature on risk analysis in SSI education, as described by Aven and van Kessenich (2020). Specifically, the results addressing **RQ1** illustrate the application of four evidence dimensions to examine reports of risk management and predictions. This use of evidence dimensions facilitated a sophisticated content analysis, providing a structured framework for parsing complex risk-related information in SSIs.

Evidence analysis focuses on the design for risk management methods (e.g., looking at the ALPS performance testing process). Evidence evaluation addresses the quality of evidence in supporting the claimed effectiveness of risk

management (e.g., if the ALPS test results sufficiently support the claimed safety of ALPS-treated water). Evidence interpretation, as the main site of argumentation on risk prediction, discusses the predicted risks in light of existing theories and models (e.g., if the ALPS-treated water's radiation level is safe in light of the radiation research and international safety standards). Evidence integration validates the adequacy of risk management methods under examination in terms of proven research and practices of risk management (e.g., if the NWR is the safest option in light of alternative waste disposal methods).

Findings from **RQ2** demonstrate how risk analysis encompasses the examination of speakers' status, positions, and potential interest relations. The analysis of the NWR controversy revealed a clear division between advocates and skeptics, aligning with Kolstø's (2001) observation that SSIs involve multiple stakeholders with divergent interests. These results highlight the complexity of determining the trustworthiness of claims, as suggested by Chinn et al. (2014), especially when stakeholders' interests may influence their positions. GOE provides a foundation for evidence use from the perspective of citizens (or knowledge consumers). Although Duncan et al. (2018) emphasized checking for scientific consensus as a form of lay evidence use, the NWR case notably lacked such consensus. Nevertheless, the findings demonstrate that lay people can still utilize evidence by focusing on speakers' potential interest relations.

Analysis of speakers yielded several insights useful for examining SSIs. Firstly, the analyzed content revealed disparate frequencies of speakers' appearances in the media. Notably, Japanese government officials and TEPCO representatives comprised the largest portion of release advocates, while scientists made up the majority of release skeptics. However, certain 'unheard' voices remain --the voices of those in and around Fukushima, who are crucial firsthand stakeholders capable of bringing reliable knowledge claims based on their lived lives in the local context. Lay use of evidence focused on speakers and contexts allows for recognition and critique of this disparity, which poses an epistemic challenge in exploring the full range of available claims and their trustworthiness. In light of the justice-oriented notion of the nature of science and knowledge construction (Gandolfi, 2024), this disparity in speaker voices should be addressed to represent "voices and experiences of communities that have been most impacted by socio-scientific challenges" (p. 18) as legitimate epistemic resources in examining controversial SSIs like NWR.

Second, attention to speakers and diversity of their claims through lay use of evidence can facilitate the examination of speakers' trustworthiness in light of their positions and interest relations. On one hand, scientists on both sides, despite their conflicting claims, exhibited unclear or neutral interest relations. This suggests a limitation in relying on publicly available resources to examine speakers' interest relations. On the other hand, the lay use of evidence in examining speaker trustworthiness helped identify Japanese government officials and TEPCO as entities whose interests converge with the successful implementation of the NWR plan. As this discussion suggests, the lay use of evidence can provide a reference for weighing the trustworthiness of claims by paying attention to their speakers.

In addition, examination of different speakers and their claims revealed the sociopolitical dimension that emerged during the content analysis. While analyzing select digital resources for statements on risk prediction, management, and communication, I identified claims that addressed risks beyond those capturable by the four evidence dimensions. For example, crucial considerations on the case of risk management failure involved the ethical considerations on the historicized suffering of human and marine lives relying on the Pacific Ocean's health. These statements considered sociopolitical aspects such as procedural appropriateness, disparate access to decision-making processes, and ethical and justice concerns related to ocean disposal of hazardous waste. Consequently, I added this sociopolitical dimension to complement the four evidence dimensions in the GOE framework. These findings that suggests the limitation of GOE or location of GOE in the analysis of risk-related competing claims resonate with Develaki's (2024) articulation of risk assessment and management that involves not only epistemic disagreements (addressed by the use of GOE) but also socio-political considerations (that should be addressed in addition to the use of GOE).

Particularly, this multidimensionality of risk-related claims present in the NWR controversy can be interpreted through the lens of socio-scientific reasoning. This type of reasoning encompasses recognizing SSI complexity, understanding reliance on ongoing scientific inquiry, considering multiple stakeholders' perspectives, and exercising skepticism towards encountered information (Sadler et al., 2007). Exploring these aspects, reasoners would be involved in rationalistic, emotive, and intuitive modes of reasoning (Sadler & Zeidler, 2005). This study's findings suggest that GOE primarily facilitates rationalistic reasoning, focusing on sophisticated examination of ongoing SSI-related inquiries. Specifically, GOE supports analysis of how these inquiries establish, justify, and communicate evidence to both experts and the general public. According to Romine et al. (2017) that conceptualized the progression of socio-scientific reasoning, GOE can be considered an effective tool for exercising skepticism in using the available data and evidence, and identifying additional evidence needed before taking sides or making decisions on SSIs.

Moreover, our findings demonstrate how engaging with an SSI through both evidence dimensions and the sociopolitical dimension can yield a more comprehensive analysis of the issue. The consideration of the sociopolitical dimension incorporates not only rationalistic but also emotive and intuitive reasoning modes (Sadler & Zeidler, 2005). This approach solicits empathy and concern for others' well-being as guiding principles when making decisions about SSIs. To maximize GOE's utility in the SSI context, therefore, it is crucial to recognize its contribution to sophisticated rationalistic reasoning on ongoing inquiries and to exercising skepticism. In addition, the use of GOE should be balanced with consideration of multiple dimensions, including sociopolitical and ethical aspects of SSIs.

Implications for SSI-Based Science Instruction

NWR is a glocal SSI–both global and local–that can have impacts on local lives and relates to global nuclear-related issues. For those with limited access to NWR information, this study's findings offer a comprehensive understanding of this situation as a global issue with significant local ramifications. To support SSI-based instruction, I provide supplementary materials in the supporting information.

NWR for SSI-based instruction can potentially align with science methods courses and secondary science classrooms. Studies have reported the use of SSIs in teacher education contexts to promote teachers' informal reasoning (Topcu et al., 2010), argumentation (Karisan et al., 2017), collaborative actions (Lee & Yang, 2019), and socio-scientific decision making (Vicente et al., 2024). Introducing GOE-informed analysis of NWR can contribute to this ongoing effort to prepare teachers for SSI-based instruction by engaging in SSIs and GOE by themselves in ways to prepare for dealing with these constructs in their current and future classrooms. Particularly, I draw attention to the findings that highlight multifaceted challenges of NWR such as procedural, social, emotional, and ethical, which gets even further complexified by the expert disagreement on the risk prediction. On the complex issues like this, teachers may effectively engage students with the sociopolitical, ethical, and emotional dimensions and leverage students' attention to their epistemic analysis of competing knowledge claims on risk prediction, assessment, and analysis.

Regarding the context engaging students in SSIs, I note not only the abundance of SSI-based science instruction as mentioned earlier (e.g., Molinatti et al., 2010; Romine et al., 2017) but also the challenges teachers may find in connecting SSIs to the standard expectations (Pedretti et al., 2008; Sadler et al., 2006). I considered how NWR could be integrated into standard informed classrooms. In the case of next generation science standards (https://www.nextgenscience.org/), two performance expectations were found to be relevant. At the high school level, NWR can be introduced in a unit addressing HS-PS1-8, covering nuclear processes including fission and radioactive decay. For middle school, NWR can be integrated into a unit aligned with MS-PS1-1, focusing on atomic composition and structures, introducing radionuclides and their unique behaviors. In these settings, NWR serves as a real-world context connected to disciplinary core ideas. Its controversial nature can be leveraged to promote science and engineering practices such as Engage in Argument from Evidence and Obtain, Evaluate, and Communicate Information.

In terms of instructional approaches, the debate between two imaginary speakers, Adrel and Skerel can provide the script for a role play. Role play has been utilized as an effective strategy to engage students in dilemmatic situations (Agell et al., 2015; Vicente et al., 2024). Students whose livelihoods are far from Japan might feel the NWR irrelevant at the beginning. The dialogue can help to familiarize with the issue or to engage in the different dimensions of dealing with evidence. For example, teachers or teacher educators can engage their students in this imaginary debate, through which students will figure out different positions, risk-related claims, and what they want to further ask. If it is science methods courses, teacher educators can use the role play as a tool for enhancing teachers' understanding of GOE.

The dialogue between Adrel and Skerel helps to familiarize students with the NWR issue and engage them in various dimensions of grasping evidence. Educators can incorporate this imaginary debate into their lessons, allowing students to explore different positions, analyze risk-related claims, and identify areas for further inquiry. In science methods courses, teacher educators can utilize this role-play approach to enhance teachers' understanding of the GOE framework. And, desirably, the instructors may move on designing instructions where students explore local risk-involving SSIs to which they can more easily relate to their own lives (Feinstein, 2011) and can act their critical citizen practices increasingly emphasized in today's world filled with risky, decision-making situations (Aven & van Kessenich, 2020; Develaki, 2024; Hansen & Hammann, 2017).

Limitations and Future Research

As I acknowledged earlier, this study poses several limitations despite the effort to elaborate the NWR as a potential resource for SSI-based instruction, and these limitations solicit follow-up research. First, in terms of data collection and analysis, the data do not fully represent the controversy over NWR, as I limited the scope of the data to news articles and the working papers of organizational representatives. While they present statements of Japanese government officials, scientists, fishing industry workers, and representatives of international organizations, they seldom introduce the voices of those whose lives will be directly (and potentially negatively) impacted by the NWR. Future research could benefit from utilizing direct interviews with experts and stakeholders to gain deeper insights into their reasoning processes. Moreover, the study's focus on a specific time frame may not capture the evolving nature of the NWR controversy. Still, the situation is likely a status quo in terms of expert disagreement. As of July 2024, the release took place 7 times. Safety reports are mainly made by the Japanese government. However, groups of activists and experts are still voicing up about potential danger, uncertain risks, and the lack of procedural transparency. The status quo further validates the need of raising awareness from global citizens.

In addition, this study did not include a classroom intervention, which limits the evaluation of the NWR's utility in SSI instruction. Although I initially conceived an instructional intervention study where teachers and students would examine the NWR, I switched to first analyzing NWR and sharing the understanding gained from the analysis. This shift was made as I soon noticed the overwhelming complexity from the competing claims over the NWR and realized the need to first parse out and discuss the complexity displayed in the public discourse, instead of taking a hasty classroom intervention that could confuse the teachers and students I would partner with. Additionally, I believed that content analysis was necessary to raise awareness of the NWR as a glocal issue that can impact not only local but also global citizens, as we are all connected by oceans, the health and prosperity of which are at potential risk. Consequently, follow-up research can design instructions for using NWR to enhance

socio-scientific reasoning, utilizing the GOE as evidentiary reasoning practices, and raising awareness of the issue.

CONCLUSION

This study presented two goals: the primary goal of articulating the NWR controversy and the subsequent goal of considering the use of this study's findings in SSI-based instruction. The first goal was achieved by elaborating on the expert disagreement in NWR, focusing on competing claims and their speakers identified from the content analysis. The findings illustrated significant disagreement with some areas of agreement. Elaborating on these disagreements can help citizens take the next step of asking necessary questions to enhance their understanding, especially regarding issues with uncertain risk predictions. Concerning the long-term goal of contributing to SSI-based instruction, I discussed the potential alignment of NWR with science methods courses and secondary science classrooms, providing supporting information that exemplifies instructional approaches.

As this study works toward meeting the two goals, the utility of GOE was demonstrated and discussed in light of the socio-scientific reasoning literature. Within the multidimensional and multimodal reasoning practices of socio-scientific reasoning, GOE can facilitate sophisticated engagement in three dimensions of socio-scientific reasoning: recognizing complexity, understanding the tentativeness of SSIs based on ongoing inquiries, and exercising skepticism towards SSI-related claims and speakers. To be useful in the context of SSI education, the use of GOE should be complemented by considering the sociopolitical and ethical perspectives involved in SSIs. Building on this work, future research can investigate the instructional approaches for exploring risk-involved SSIs so as to support students and the public in making conscientious, science-informed decisions about SSIs.

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APPENDIX A

Table A1. Supplementary information 1. Knowledge claim codes in each evidence dimension

ED	Release advocate (total N = 18)	Release skeptic (total N = 23)
Evidence analysis	N = 4 · ALPS's performance for filtering radioactivity was rigorously tested multiple times. · Radionuclides released into the ocean will be diluted, decreasing radioactivity levels significantly. · TEPCO has fully disclosed the ALPS procedure and monitoring plan. · The inspection of the ALPS system was replicated by multiple labs worldwide.	N = 3 · There is a lack of transparency and rigor in showing the treatment process. · More information is needed about how the water was sampled and pre- and post-tested. · TEPCO should disclose the means by which they tested the reduction of radioactivity.
Evidence evaluation	N = 6 · ALPS filtered 62 out of 64 radionuclides in the Fukushima nuclear-contaminated water. · Only tritium and carbon-14 remain after filtration. · Tritium can't be filtered because it is part of discharged water. · The amount of tritium in the treated water is very small. · The IAEA conducted an impartial and scientific review to ensure rigorous inspection. · TEPCO is reliable to operate ALPS.	N = 6 · The inspection result details are unavailable to the broader scientific community. · TEPCO has rejected offers from independent researchers to perform peer reviews. · TEPCO previously acknowledged that Fukushima water contains radionuclides other than tritium and carbon-14. · Other radionuclides are not reported in detail. · The claim about ALPS's effectiveness can't be justified due to lack of accessible evidence. · The process conducted by scientists affiliated with IAEA is unlikely trustworthy.
Evidence interpretation	N = 4 · The tritium level in ALPS-treated water falls below the most rigorous international standards. · The amount of tritium is too small (to ingest and bioaccumulate). · Some studies say that tritium, when ingested, does bioaccumulate and increase cancer risks. · Studies show that minimal radiation exposure is natural and normal.	N = 7 · Standards don't guarantee safety. · Various national and international standards exist set up by considering multiple factors, including scientific, diplomatic, and political ones. · The long-term release planned for NWR is unprecedented. · Studies on long-term releases like NWR spanning three to four decades are lacking. · There's uncertainty about how ocean-released tritium might bioaccumulate in the marine food web, given its 12.3-year half-life. · The long-term effects of tritium on humans are uncertain. · Doubts persist about ALPS's complete filtration of non-tritium radionuclides, as some remain harmful even in trace amounts.
Evidence integration	N = 4 · These methods are similar to those widely used in ocean disposals at regular nuclear power plants. · Historically, other countries with nuclear power plants have produced and released contaminated water into the ocean. · NWR is the most realistic option. · NWR is safer than alternatives that could pose even greater health and environmental risks.	N = 7 · Fukushima nuclear meltdown differs from regular nuclear powerplant operation. · This level of nuclear contamination like Fukushima explosion does not occur as part of regular waste disposal at other nuclear plants. · At Fukushima, the water was directly exposed to and significantly contaminated by radionuclides. · Other disposal methods were not fully considered. · After Chernobyl, the disposal method involved solidifying the waste. · Solidifying the waste is believed to be less detrimental than releasing it into the ocean. · Releasing waste into the ocean allows radionuclides to easily spread. · If the ALPS-filtered water is so safe, reuse it for Japan's domestic water needs.

Note. ED: Evidence dimensions (Duncan et al., 2018)

Table A2. Supplementary information 2. Socio-political claim codes

Release advocate	Release skeptic
N = 5	N = 5
· NWR is the most efficient solution to manage space occupied by nuclear waste. · IAEA has committed to ongoing, rigorous monitoring of ALPS. · TEPCO will keep reporting the monitoring result. · The Japanese government will support the recovery of the fishery industry. · NWR policy should not be used as a pretext for diplomatic tensions.	· TEPCO is not qualified to operate ALP because TEPCO bears significant responsibility for the 2011 Fukushima nuclear meltdown. · As a global precedent for large-scale wastewater disposal, NWR requires transparent communication with affected communities about potential scenarios and contingency plans. · The ocean is a vital ecosystem and holds cultural significance for many. · We must not repeat historical injustices inflicted upon Pacific communities. · Justifying the release of hazardous materials into the ocean based on historical precedent is unethical and irresponsible.

Supplementary Information 3

Suggestion for integrating NWR (nuclear wastewater release) into SSI-informed instruction

Instructors note: Consider the subject context, grade level, and students' (or teachers') learning goals in modifying and using this activity

Standard connection: NGSS performance expectations

Instructors note: Consider the standard connection for the secondary science context

1. **HS-PS1-8.** Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
2. **MS-PS1-1.** Develop models to describe the atomic composition of simple molecules and extended structures.

Instructional storyline (high school example)

The instruction could begin with an introduction to the Fukushima nuclear accident, using it as a real-world context to explore nuclear fission. Students would then develop models illustrating the process of nuclear fission in reactors and how it generates energy. This would be followed by an explanation of how the accident led to the creation of radioactive wastewater, introducing the concept of radioactive decay. Students could model different types of radioactive decay and calculate half-lives of various isotopes found in the wastewater. The lesson would then transition to the NWR issue, discussing how ALPS works to filter out radionuclides and the challenges of managing long-lived isotopes. Throughout the lesson, students would be encouraged to connect their models of nuclear processes to the real-world problem of nuclear waste management, culminating in a discussion of the potential environmental impacts and societal implications of the NWR decision.

Opening discussion

What is a socio-scientific issue?: SSIs are important science-related topics that affect both individuals and society. These issues are complex, often controversial, and don't have clear answers. By learning about SSIs, students can make better decisions and take thoughtful actions that will positively impact their own lives as well as their local and global communities.

1. Why do you think people say these issues are complicated, controversial, and don't have clear answers?
2. Can you think of any science-related issues from your neighborhood or the news?
3. Why do you think the issues are important and related to science?

Preview vocabulary

Table A3. Preview vocabulary

Category	Vocabulary
Natural disaster	Earthquake and Tsunami
Nuclear power and power plant	Nuclear plant, nuclear reactor, nuclear energy, fission, cooling water system, and nuclear meltdown
Radiation	Radioactive, radionuclides, isotope, half-life, and nuclear waste
Fukushima nuclear water release related	ALPS, TEPCO, and IAEA
Engaging with the real-life issue	SSI, socio-scientific reasoning, knowledge claims, GOE, evidence dimension, socio-political dimension, ethics, justice, responsibility

Discuss before the SSI scenario

1. Have you heard about nuclear power plant accidents?
2. What do you think will be a nuclear meltdown?
3. What have you heard about the radioactivity or radiation?

Introduce the SSI

NWR to the Pacific Ocean as an SSI: On March 11, 2011, a huge earthquake and tsunami hit northeast Japan. This badly damaged the power supply at the Fukushima nuclear plants. Without power, the cooling system stopped working, which made the nuclear reactors get too hot and melt down. Usually, cooling water moves around the reactors without touching them. But because of the meltdown, the water touched the hot reactors directly. This made the water very radioactive. The radiation spread through the whole power plant and even to nearby areas.

For over ten years, Japan's government tried to figure out what to do with all this radioactive water. They finally decided to clean it up and release it into the Pacific Ocean. They said they would use a special filtering system called ALPS to filter out radionuclides from the water.The company that runs the power plant, TEPCO, built ALPS. They say it can remove 62 out of 64 types of radionuclides from the water. An IAEA, the organization seeking to promote nuclear energy, was asked to test ALPS. IAEA tested its performance, and said it worked well. Upon IAEA's positive test result, on August 24, 2023, Japan started releasing the water into the ocean. They think this will take 30 to 40 years to finish.

But the release didn't begin with experts' consensus on the safety claimed by the Japanese government, TEPCO, or IAEA. There are different kinds of experts involved, not only Japan's government officials, TEPCO company representatives, or IAEA but also scientists who study nuclear power, ocean life, and the environment, as well as local people who fish for a living. Some experts think the released water will be safe enough to release. Others request more studies because of the uncertainty in predicting the harms from such a long term release to the Pacific Ocean.

Resources

1. Nogrady, B. (2023). Is Fukushima wastewater release safe? What the science says. *Nature*. https://doi.org/10.1038/d41586-023-02057-y
2. Normile, D. (2021). Japan plans to release Fukushima's wastewater into the ocean. *Science*. https://doi.org/10.1126/science.abi9880

Discuss after reading the scenario (1)

1. What is the main problem in the issue of releasing nuclear wastewater to the Pacific Ocean?
2. Who are the people or groups that might care about or be affected by this issue?
3. What things are you curious about or unsure of in this situation?
4. If someone asked you whether you support or oppose the plan to release nuclear wastewater into the ocean, what information would you want to know before making up your mind?

Discuss after reading the scenario (2)

Table A4. Speaker professions and their positions on NWR

Speaker profession and status	Release advocate	Release skeptic
National representatives (N = 11)	9 Japanese government official	1 China government official & 1 Korean citizen representative
Company (N = 5)	1 TEPCO representative	3 Japanese Fishermen & 1 Korean Fisherman
International organizations (N = 3)	1 IAEA representative	1 PIF* representative & 1 Greenpeace representative
Scientists (N = 18)	4	14
Total (N = 37)	**15**	**22**

Note. PIF: Pacific Islands Forum & *PIF is an international organization comprising 16 countries in the Pacific Region (PIF aims to secure their countries' political and economic success, and environmental safety protected from ocean contamination)

Table A4 shows different people and groups who either support or oppose the plan to release the filtered water from Fukushima into the ocean.

1. What do you notice reading the table? What do you want to ask?
2. What do you think might be influencing their positions?
3. Who's perspectives should be further considered before deciding to release the ALPS-filtered water from Fukushima into the ocean?

Engage students in a role play

Instructors can use the dialogues in varying ways to serve the particular learning goals.

Two actors: Adrel (release advocate) and Skerel (release skeptic).

Dialogues

1. Sociopolitical dimension
2. Evidence analysis dimension
3. Evidence evaluation dimension
4. Evidence interpretation dimension

5. Evidence integration dimension

Dialogue 1

Adrel: Releasing the water into the ocean is the most realistic solution to free up the space at Fukushima regions. It's similar to how we've handled hazardous waste in the past.

Skerel: Just because we've done something before doesn't make it right. We shouldn't repeat past mistakes.

Adrel: It's not a mistake. The IAEA and TEPCO will manage it carefully.

Skerel: But TEPCO isn't trustworthy. They're the company responsible for the 2011 nuclear accident. And this plan to release water will last for decades – that's never been done before!

Adrel: Don't worry, the Japanese government will keep everyone informed. They've promised to help fishermen if people become afraid to eat seafood.

Skerel: This isn't just about fear. It's about what's right for people and the environment. Pacific island communities have already suffered from radiation in the past. We can't let that happen again.

Adrel: You're making it sound worse than it is. Some countries might be against this plan for their own reasons, but this isn't about politics. Japan should be allowed to release the water.

Dialogue 2

Skerel: How was the nuclear wastewater sampled? How was the radioactivity measured before and after the water being filtered through ALPS? The process testing the ALPS's filtration ability should be transparently reported.

Adrel: TEPCO, who runs ALPS, has shared all their procedures. The test took place at multiple labs over the world. And the IAEA as an independent institution did a thorough review.

Skerel: Ok, then please show us. How did TEPCO and the labs test ALPS? They should show transparently how they tested for reduced radioactivity.

Dialogue 3

Adrel: ALPS removed 62 out of 64 radionuclides from the water! Only tritium and carbon-14 remain after filtration. Tritium can't be filtered because it is part of discharged water, but the amount of tritium in the treated water is very small.

Skerel: We can't verify what you say because TEPCO hasn't shared detailed results with other scientists. They've turned down offers for independent reviews. Why aren't all the test results reported in detail?

Adrel: TEPCO didn't reject reviews. They just let the best scientists, chosen by the IAEA, do the testing.

Skerel: But I am not sure if we can just trust the results based on what you say… IAEA isn't a scientific organization. It's an agency aimed to promote the nuclear power business. Who are the scientists? How are they independent from IAEA or the Japanese Government?

Dialogue 4

Adrel: The radioactivity level in ALPS-treated water falls below the most rigorous international standards.

Skerel: Standards don't always mean it's safe. They're often influenced by politics, not just science.

Adrel: Regardless of the standards, the quantity of tritium in the ALPS-filtered water is too small. Although some studies say that tritium, when ingested, does bioaccumulate and increase the risk of cancer risks, the amount of tritium in the ALPS-filtered water is too small to ingest and bioaccumulate. And studies show that minimal radiation exposure is natural and normal.

Skerel: But what about long-term effects? We've never released water like this for decades before. With tritium's 12.3-year half-life, we're uncertain how ocean-released tritium might bioaccumulate in the marine food web and ultimately affect humans. And what about other radionuclides claimed to be completely filtered by ALPS, given that even trace amounts of some are known to be highly detrimental?

Dialogue 5

Adrel: The methods used in ALPS are not new. They are similar to those widely used in ocean disposals at regular nuclear power plants. Other countries with nuclear power plants have also produced and released nuclear wastewater into the ocean.

Skerel: However, Fukushima's nuclear-contaminated water differs from the water produced by typical nuclear power plants. At Fukushima, the water was directly exposed to and significantly contaminated by radionuclides, unlike the regular waste disposal at other nuclear plants.

Adrel: But for the Japanese government needing to free up the on-land space and secure safety, NWR is the most realistic option. And it is safer than alternatives that could pose even greater health and environmental risks.

Skerel: How so? I know there were about 5 options or so considered for the Fukushima wastewater disposal. Were the alternatives fully considered? For instance, after Chernobyl, the disposal method involved solidifying the waste, which is believed to be less detrimental than releasing it into the ocean, where radionuclides can easily spread. So why not solidification? Or, If the ALPS-filtered water is so safe and radiation-free, why not reuse it for Japan's domestic water needs?

Discussion after a role-play

1. What's the focus of each dialogue in your thought?
2. What questions do you have now having engaged in the role play?
3. Which position between Adrel and Skerel do you think is more trustworthy? And why?
4. Based on this information from Adrel and Skerel, would you take side for or against the wastewater release to the Pacific Ocean?

Instructor guideline: Evidence dimensions and socio-political dimension

Consider the grade level and learning goals to modify and share the table.

When the instruction takes place in methods courses, introducing the below outline of GOE can help.

Table A5. Evidence dimensions and socio-political dimension

	Description	Examples
Evidence dimensions		
Evidence analysis	The statement addresses components of the ALPS performance inspection process for filtering radionuclides from wastewater, or the coherence between the inspection design and the safety claims being tested.	Statement focuses on or is relevant to: · methods used for wastewater sampling, · methods used to measure and analyze radionuclide types and amounts before and after ALPS filtration, · transparency in reporting the whole process of ALPS performance inspection to independent experts, · transparency in reporting filtration results to independent experts and subjecting them to peer review, · ALPS filtering mechanisms
Evidence evaluation	The statement addresses the quality, reliability, and validity of the ALPS inspection results comparing pre- and post-filtration radionuclide levels, considering alternative explanations for these results.	Statement focuses on or is relevant to: · adequacy of wastewater sample size in representing the original wastewater composition, · reliability of measurement tools in detecting concerning radionuclides, · specific types of radionuclides successfully filtered by ALPS, · presence of any high-risk radionuclides remaining after filtration, · proportion of residual radionuclides post-filtration · magnitude of change in radiation levels before and after ALPS filtration
Evidence interpretation	The statement addresses the strength of the ALPS inspection results in supporting safety claims, in relation to international safety standards or theories of radiation risks.	Statement focuses on or is relevant to: · strength of inspection results supporting the claimed safety, · validity of the claimed minimal to non-existent risk in relation to international safety standards, · accuracy of the predicted minimal to non-existent risk when considered against theories of radiation impacts on human health and marine ecosystems, · assessment of uncertainty in risk prediction, given the unprecedented duration of the planned release

Table A5 (Continued). Evidence dimensions and socio-political dimension

	Description	Examples
Evidence integration	The statement examines waste disposal research and practices, including radiological literature, existing disposal methods, and alternative options proposed for Fukushima wastewater disposal.	Statement focuses on or is relevant to: · consideration of post-filtration radioactivity levels in the context of studies on long-term, low-dose radiation exposure effects. · comparison between ALPS and existing nuclear wastewater disposal strategies. · comparison of the safety level between ALPS and alternative proposed methods for Fukushima wastewater disposal.
Socio-political dimension		
	The statement addresses social, procedural, and ethical aspects, beyond justifying or critiquing knowledge claims.	Statement focuses on or is relevant to: · appropriateness & fairness in decision making · responsibility and eligibility of ALPS management · view on NWR in terms of ethics, justice, responsibility

Resources for instructional design

1. Nogrady, B. (2023). Is Fukushima wastewater release safe? What the science says. *Nature*. https://doi.org/10.1038/d41586-023-02057-y
2. Normile, D. (2021). Japan plans to release Fukushima's wastewater into the ocean. *Science*. https://doi.org/10.1126/science.abi9880