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David C. Owens
Georgia Southern University, dcowens@georgiasouthern.edu

Destini N. Petitt
University of North Carolina at Charlotte, dpetitt@uncc.edu

Diane Lally
University of Nebraska - Lincoln, dlally@huskers.unl.edu

Cory T. Forbes
University of Nebraska - Lincoln, cforbes3@unl.edu

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Article

Cultivating Water Literacy in STEM Education: Undergraduates' Socio-Scientific Reasoning about Socio-Hydrologic Issues

David C. Owens [1,*], Destini N. Petitt [2], Diane Lally [3] and Cory T. Forbes [3]

[1] Department of Middle Grades and Secondary Education, Georgia Southern University, Savannah, GA 31419, USA
[2] Department of Geography and Earth Science, University of North Carolina at Charlotte, Charlotte, NC 28223, USA; dpetitt@uncc.edu
[3] School of Natural Resources, University of Nebraska, Lincoln, NE 68583, USA; dlally@huskers.unl.edu (D.L.); cforbes3@unl.edu (C.T.F.)
* Correspondence: dcowens@georgiasouthern.edu

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Abstract: Water-literate individuals effectively reason about the hydrologic concepts that underlie socio-hydrological issues (SHI), but functional water literacy also requires concomitant reasoning about the societal, non-hydrological aspects of SHI. Therefore, this study explored the potential for the socio-scientific reasoning construct (SSR), which includes consideration of the complexity of issues, the perspectives of stakeholders involved, the need for ongoing inquiry, skepticism about information sources, and the affordances of science toward the resolution of the issue, to aid undergraduates in acquiring such reasoning skills. In this fixed, embedded mixed methods study (N = 91), we found SHI to hold great potential as meaningful contexts for the development of water literacy, and that SSR is a viable and useful construct for better understanding undergraduates' reasoning about the hydrological and non-hydrological aspects of SHI. The breadth of reasoning sources to which participants referred and the depth of the SSR they exhibited in justifying those sources varied within and between the dimensions of SSR. A number of participants' SSR was highly limited. Implications for operationalizing, measuring, and describing undergraduate students' SSR, as well as for supporting its development for use in research and the classroom, are discussed.

Keywords: socio-hydrological issues; socio-scientific reasoning; functional scientific literacy

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1. Introduction

Globally, societies face increasing natural-resource-related challenges associated with the food–energy–water nexus [1]. Considering the rapidly expanding human population, which now impacts all ecosystems on Earth [2], these challenges are expected to intensify, leading to increased tension and competition for natural resources [3]. In order to effectively confront these challenges, global citizens must be equipped with the knowledge and reasoning skills necessary to make informed, science-based decisions, and for this reason, science, technology, engineering, and mathematics (STEM) education historically foregrounded the teaching and learning of disciplinary concepts. However, a grasp of the scientific aspects of many of today's pressing issues is often insufficient to confront pressing transdisciplinary global challenges [4], as important societal aspects of these issues that may not be scientific in nature (e.g., moral, political, and economic) contribute to the complexity of these issues and must also be addressed if such issues are to be effectively resolved [5]. As a result, these issues are often framed as being socio-scientific issues (SSI), the consideration of which is informed by an understanding of science but also necessitates the evaluation of societal considerations [6], including reasoning about the complexity of the issue, the diverse and often opposing views of all stakeholders involved, the need for ongoing inquiry into the SSI and skepticism when considering media sources, as well as the affordances of science and non-science considerations toward the resolution of the SSI. Together, these five dimensions of reasoning about SSI comprise the socio-scientific reasoning construct (SSR) [7], a suite of practices that contribute to the thoughtful negotiation of SSI.

Across the gamut of SSI contexts, water is perhaps the most crucial of elements, so water-related SSI, or socio-hydrological issues (SHI) [3], may require a more domain-specific focus. The abundance, quality, and availability of water influences all human and natural systems [8], and is an important focus of standards for science teaching and learning [9,10] and of research regarding students' learning about water and water systems [11–13]. Adding to the complexity of SHI is that "we do not know how to resolve the greatest hydrological challenges in the world ... to simultaneously ensure hydrological, economic, social, and environmental sustainability" [2] (p. 4030). For this reason, functional water literacy, like its more domain general counterpart, science literacy, involves the evaluation of hydrological knowledge (e.g., "water move through environmental systems and interact[ion] with other substances," [14] (p. 37)) concomitantly with aspects of contemporary SHI that are not hydrological in nature—if informed position-taking and decision-making about SHI is to become commonplace [15,16]. Given that the socio-scientific reasoning construct has served as an effective means for the concomitant development of conceptual science knowledge about science and practice skills for considering the non-science aspects of socio-scientific issues (i.e., functional scientific literacy, [17,18]), then socio-scientific reasoning about socio-hydrological issues would be expected to serve in a similarly effective manner toward the development of a water-literate society. Interestingly, few studies have investigated students' SSR about SHI, particularly among undergraduates [19,20]. In this article, we seek to fill that gap by exploring the potential for a regionally relevant SHI to serve as a meaningful context for the development of functional water science literacy through SSR.

1.1. Research on Teaching and Learning about Water

As recognized by the National Science Foundation, "All human and natural systems are influenced by the distribution, abundance, quality, and accessibility of water" [8] (pg. 6). As such, most of the world's most pressing contemporary challenges associated with STEM and food, agriculture, natural resource, and human sciences share a grounding in water and water systems. It is therefore essential that global citizens develop a conceptual understanding of both hydrologic phenomena and socio-hydrological systems [21], or the interrelationships between natural water systems and their human dimensions. Both are reflected in standards for science teaching and learning that span K-12 and postsecondary educational settings (e.g., [9,10]). However, prior research has shown that students often struggle to understand water-related concepts [14,22–25]. These trends persist in the general public, where significant numbers of US adults exhibit a limited understanding of components and processes of the global water cycle, as well as water resource use by humans [26]. Therefore, a need exists for enhanced, systemic efforts to cultivate functional water literacy in formal educational settings.

1.2. Theoretical Framework for Socio-Scientific Reasoning

Our theoretical framework is grounded in situated learning theory [27], which posits that knowledge is not easily abstracted when learned out-of-context for use elsewhere when a particular situation demands it. Rather, learning is situated and even embedded in the culture, context, and activity in which its use is requisite [28], such that learning may even be unintentional as opposed to deliberate [29]. Given that understanding and effectively responding to SSI requires sophisticated reasoning about their science and non-science aspects (i.e., functional scientific literacy), SSI serve as the authentic contexts in which the desired learning and practice need be situated [30].

An SSI-based approach to instruction that foregrounds the development and employment of scientific knowledge and research has shown its impact on a number of student outcomes, including increases in science content knowledge [31,32], the nature of science understanding [33], and science practices skills (such as modeling-based reasoning [34], explanation construction [35], and argumentation and discourse [36]). However, although a solid grasp of conceptual knowledge and science practice skills have traditionally defined scientific literacy, these are necessary but insufficient for resolving today's global challenges [5]. For many of these issues, numerous potential solutions exist, none of which equally impact all relevant stakeholders. As a result, staking positions and making decisions about these SSI requires moral and ethical judgements to be made alongside STEM considerations, if they are to be effectively resolved.

From this perspective, scientific literacy encompasses more than just the ability to "describe, explain, predict, and use evidence to argue about natural phenomena [and] pose and evaluate arguments based on evidence" [37] (p. 22)—the content knowledge and practices skills requisite to understanding SSI—it also includes a suite of reasoning skills that deal with societal ramifications of the issue and potential solutions [17]. For example, informed individuals should also be able to recognize the complexity of SSI and account for the diverse and often opposing perspectives of different stakeholders involved in SSI, and would likely be affected by any proposed resolution. Additionally, because SSI are dynamic and open-ended, informed consideration of SSI requires ongoing inquiry that must be guided with a skeptical eye toward potentially biased reporting of information. Such a suite of skills would be expected to aid citizens in blending their understanding of SSI from a science and engineering perspective with those socio-cultural considerations that are requisite to the successful resolution of those SSI. Sadler and colleagues [7] conceptualized the ''socio-scientific reasoning" construct to account for such practices, which included complexity, perspective taking, inquiry, and skepticism, and more recently, the affordances of science and non-science considerations toward resolving SSI to complement scientific reasoning when considering and resolving SSI (See Table 1 for operational definitions of each dimension of SSR).

Table 1. Operational definitions of each dimension of socio-scientific reasoning (SSR) (adapted from [16] p. 3).

SSR Dimension	Operational Definition
Complexity	The recognition that SSI are open-ended problems that lack simple solutions, that SSI possess an emergent systemic quality that makes them inherently complex, and that resolution cannot be achieved by addressing isolated factors.
Perspective taking	The acknowledgement that complex, multi-faceted SSI may be perceived differently by interested parties, and that successful resolution requires the consideration of diverse and often opposing scientific and non-scientific viewpoints.
Inquiry	The appreciation that SSI are ill-structured and indeterminate because they entail complex social considerations and are undergirded by frontier science, and therefore, SSI should be subject of ongoing inquiry and investigations as a way of disentangling and mitigating these sources of uncertainty.
Skepticism	The scrutinization of information sources as to their trustworthiness, including the identification of potential biases; weighing of the robustness of evidence; and the integration of scientific and social factors influencing SSI information sources, including scientists' reporting.
Affordances of science and non-science considerations	The awareness of ways that science can and cannot account for natural phenomena associated with SSI, and the extent to which science, as compared with other considerations such as sociocultural factors and ethical commitments, can appropriately provide avenues for SSI resolution.

Since their introduction, a number of studies have sought to shed light on individuals' abilities to reason about SSI. Students have generally been able to recognize the complexity of SSI as well as the perspectives of the stakeholders involved. However, many have struggled to grasp the inherent uncertainty around SSI, acknowledge the need for ongoing inquiring into SSI so as to become and remain informed about them, or employ sound reasoning regarding that which an understanding of science affords toward being informed about an issue and developing potential resolutions that have a high chance of success [7,38]. Karahan and Roehrig also found students to be more skeptical about non-scientific information than they were about scientific reports, but those students also recognized that science, too, can be biased based on funding sources and vested interests [39]. Interestingly, the positions those students took regarding SSI affected their ability to reason about them, but interdisciplinary collaboration within and across individuals from different walks of life can aid in the sharing of perspectives and contribute to students' development of SSR [40]. Furthermore, a recent study by Kinslow and colleagues [41] demonstrated that the sophistication of students' SSR significantly increased upon completion of a six week SSI-oriented field ecology class. These findings contribute to a growing body of evidence that suggests great potential for learning experiences directed at the enhancement of functional scientific literacy in the context of SSI.

1.3. SSR about SHI

Water-literate individuals are expected to effectively reason about the hydrologic concepts that underlie water-related SHI, but functional water literacy requires concomitant reasoning about the societal, non-hydrological aspects of SHI that must also be addressed in order for the SHI to be effectively resolved [17,18]—reasoning that should bolstered by reference to a breadth of sources (e.g., ethics, economics, politics, etc.) and accompanied by justification as to their relevance to the issue, which provides depth to their reasoning. Given that SSI have generally served as meaningful contexts for students' to better understand the science concepts that underlie SSI, as well as for reasoning about societal aspects of SSI by way of engagement in SSR (i.e., functional scientific literacy), we would expect SHI to serve similarly as meaningful contexts for the development of functional water literacy. Studies have begun to emerge that illustrate some of the criteria students consider when making decisions about the resolution of SHI [19], systems thinking they employ [42], and how their personal values inform their reasoning [20]. However, the potential for the SSR construct to provide a concrete means for developing functional water literacy in the context of SHI is underexplored, particularly in undergraduate courses with a direct focus on water.

1.4. Purpose of Study

The purpose of this study was to better understand the potential for SHI to serve as a meaningful contexts for undergraduates' engagement in reasoning about hydrological and non-hydrological aspects of SHI that is requisite to functional water literacy. This investigation is unique in that it is among the first to explore the potential for the SSR construct to serve as a viable means for students to meaningfully consider the hydrological and non-hydrological aspects of SHI that are requisite to their resolution specifically, and to the development of functional water literacy more generally. The following research question guided our investigation:

How do undergraduates engage in SSR about the hydrological and non-hydrological aspects of a regionally-relevant SHI?

2. Materials and Methods

2.1. Research Design

A fixed, embedded mixed methods design was employed to meet the stated purpose of the study [43]. First, a quantitative analysis was employed to determine the range of SSR sophistication that participants' exhibited. This was accomplished by evaluating participants' SSR with a rubric to quantify depth of sophistication through the identification of reasoning sources and their justification for each SSR dimension. SSR that was evaluated to be at the highest level of sophistication for each dimension as indicated by the rubric was then analyzed thematically to account for the breadth of hydrological and non-hydrological sources of reasoning those participants employed [44]. This research design was expected to contribute completeness and complementarity to the study findings by providing qualitative illustration of the sophistication of SSR as determined quantitatively [45,46], thus aligning it with the purpose of the study.

2.2. Context of Study

This study was conducted over two consecutive semesters in a medium-enrollment, introductory, interdisciplinary course open to STEM and non-STEM students at a large Midwestern university. The course (blinded for peer review, [47]) was designed specifically to provide undergraduate students opportunities to build knowledge about both natural and human dimensions of Earth's water systems and complex, real-world, water-related issues. One of the key goals of this course was to attract both STEM majors and non-majors, and teach them content knowledge, the importance of water, and how to use that knowledge to reason about SHI. The course was developed in accordance with the SSI Framework for Teaching and Learning [48] and involved a suite of assignments, projects, and activities through which students engaged with contemporary SHI. For example, in one particular sequence, students were introduced to the science and societal aspects of the Flint water crisis, a contemporary SHI involving prolonged exposure to lead-laden drinking water. Throughout the course, students considered concepts in hydrology (e.g., basic water science and practices, such as modeling), as well as consideration of and discourse about water policy, history, and urban water management, in the context of various SHI. This positioned students to gain significant experience evaluating socio-hydrological aspects of issues, such as the Flint water crisis, and accounting for those considerations in the solutions they proposed. As these experiences informed students' SSR about the Flint water issue, they also allowed for their development and practice of SSR. Students had the opportunity to showcase the SSR skills they had developed throughout the course in a final assessment, where they were tasked with considering a regionally relevant SHI, the Raccoon River nitrates issue. Significant gains in undergraduates' hydrological content knowledge resulting from SHI-oriented instruction delivered in this course have previously been reported (e.g., [47]). The focus of this study is on the potential for the SSR construct to elicit reasoning about hydrological and non-hydrological aspects of SHI through engagement in SSR.

2.3. Participants

Ninety-one of the 98 undergraduate students enrolled in the three-credit hour-long course participated in the study during the first (n = 38) and second (n = 53) year the course was offered (Table 2). Our goal of including STEM and non-STEM students in the course was achieved through the enrollment of journalism, history, agribusiness, pre-health, and fisheries and wildlife biology majors. The students comprising the class were diverse, including local students from urban, suburban, and rural backgrounds, as well as a significant number of international students. This unique combination of students afforded a rich socio-cultural context in which to facilitate innovative, interdisciplinary science teaching and learning.

Table 2. Student demographic data by semester.

Year	Gender		Class			
	Female	Male	Freshman	Sophomore	Junior	Senior/+
First	16	22	10	11	9	8
Second	30	23	2	28	15	8
Total	46	45	12	39	24	16

2.4. Data Collection

SSR was introduced as "a theoretical construct designed to uniquely capture the array of practices fundamental to the negotiation of SSI" [7] (p. 377), and the Quantitative Assessment of Socio-Scientific Reasoning (QuASSR, [48]) was developed as a means for measuring it. The QuASSR is comprised of a scenario that relates information about a particular SSI, followed by polytomous items that elicit each of the five dimensions of SSR. Each of the items is two-tiered, including a forced-response item (e.g., a "yes or no" question) followed by an open-ended response item to elicits the reasoning behind the initial forced-choice response. The QuASSR has been found to provide valid information about students' SSR that is useful for researchers and practitioners seeking to capture the kinds of reasoning that are requisite to functional scientific literacy [49].

For this study, the QuASSR was framed around a one-page scenario about a regionally relevant SHI, the Raccoon River Nitrates Issue (RRNI), where residents of Des Moines, IA who get their drinking water from the Raccoon River, must treat the water for the high levels of nitrates that drain into the river from corn farms in the watershed upstream. High nitrate levels negatively affect riverine ecosystems, consumption of nitrate-laden water reduces the blood's ability to deliver oxygen to the cells of those individuals that consume it, and there are significant financial costs associated with seasonal treatment of nitrate-laden water for municipal use. Additionally, non-science aspects complicate the resolution of the RRNI, including the politics and history of water rights and responsibility, the economics of treating water for nitrates and changing farming practices, and ethical aspects of assigning responsibility. Informed reasoning about the Raccoon River nitrate issue includes recognizing, evaluating, and addressing both science and non-science aspects of the issue—all of which are requisite to its resolution. The scenario is followed by five open-ended items, each addressing one of the five dimensions of SSR as described in the theoretical framework (i.e., complexity, perspective taking, inquiry, skepticism, and the affordances of science). Given the focus of the study on the potential for the SSR construct to elicit reasoning about hydrological and non-hydrological aspects of SHI through engagement in SSR, the most appropriate instance to elicit participants' most informed SSR was at the end of the semester. Thus, participants completed the RRNI QuASSR once as part of the course summative assessment, which involved participants' reading the one-page scenario and responding to the five items (the RRNI QuASSR instrument can be accessed in the Supplementary Materials, Figure S1).

2.5. Data Analysis

We used an *a priori*, five-point rubric (0–4) to account for the depth of reasoning students exhibited for each dimension of SSR (Table A1), as has been employed in previous studies (see [16,50] for more), to increase the reliability of the scoring [51]. A maximum score of four was awarded to responses that provided two sources of reasoning regarding a particular dimension of SSR, with each elaborated on and/or justified as to their importance in resolving the issue. Two reviewers independently evaluated each response before discussing and reaching consensus regarding any and all scores that differed. Exemplars typifying each level of reasoning, or 'depth of SSR', for each dimension as indicated by the QuASSR rubric can be accessed in the Supplementary Materials (Tables S1–S5).

Then, responses that were evaluated to be at the highest level of sophistication for each SSR dimension as indicated by the rubric were analyzed thematically to account for the breadth of hydrological and non-hydrological sources of reasoning those participants employed [44] when considering the RRNI. As part of the thematic analysis, two researchers independently analyzed the responses noting any sources of reasoning for each SSR dimension. Then, researchers compared their notes and reached consensus to codify the sources of reasoning present in each response. Those sources of reasoning that informed each SSR dimension, as well as participant responses exhibiting the widest breadth of SSR, are shared below.

3. Results

In the results that follow, we present undergraduates' reasoning about the RRNI regarding each of the five dimensions of SSR (i.e., complexity, perspective taking, inquiry, skepticism, and affordances of science). Findings are shared with a focus on the various sources of reasoning that appeared in participants' responses (hydrological and non-hydrological) and the depth of reasoning exhibited. Participants' responses to the SHI touched on a breadth of reasoning sources and exhibited varied sophistication across SSR dimensions (Table 3; Figure 1). For example, although an overwhelming majority of the participants provided sophisticated reasoning about the perspectives that stakeholders in the issue would be expected to take, the skepticism exhibited by participants about the sources of information they perused was quite limited. In fact, nearly half failed to exhibit any skepticism whatsoever. SSR related to complexity, inquiry, and the affordances of science were more evenly distributed. Tables of exemplar quotes representing the different levels of reasoning sophistication (i.e., depth of SSR) can be found in Table S3. Findings are organized by SSR dimension below.

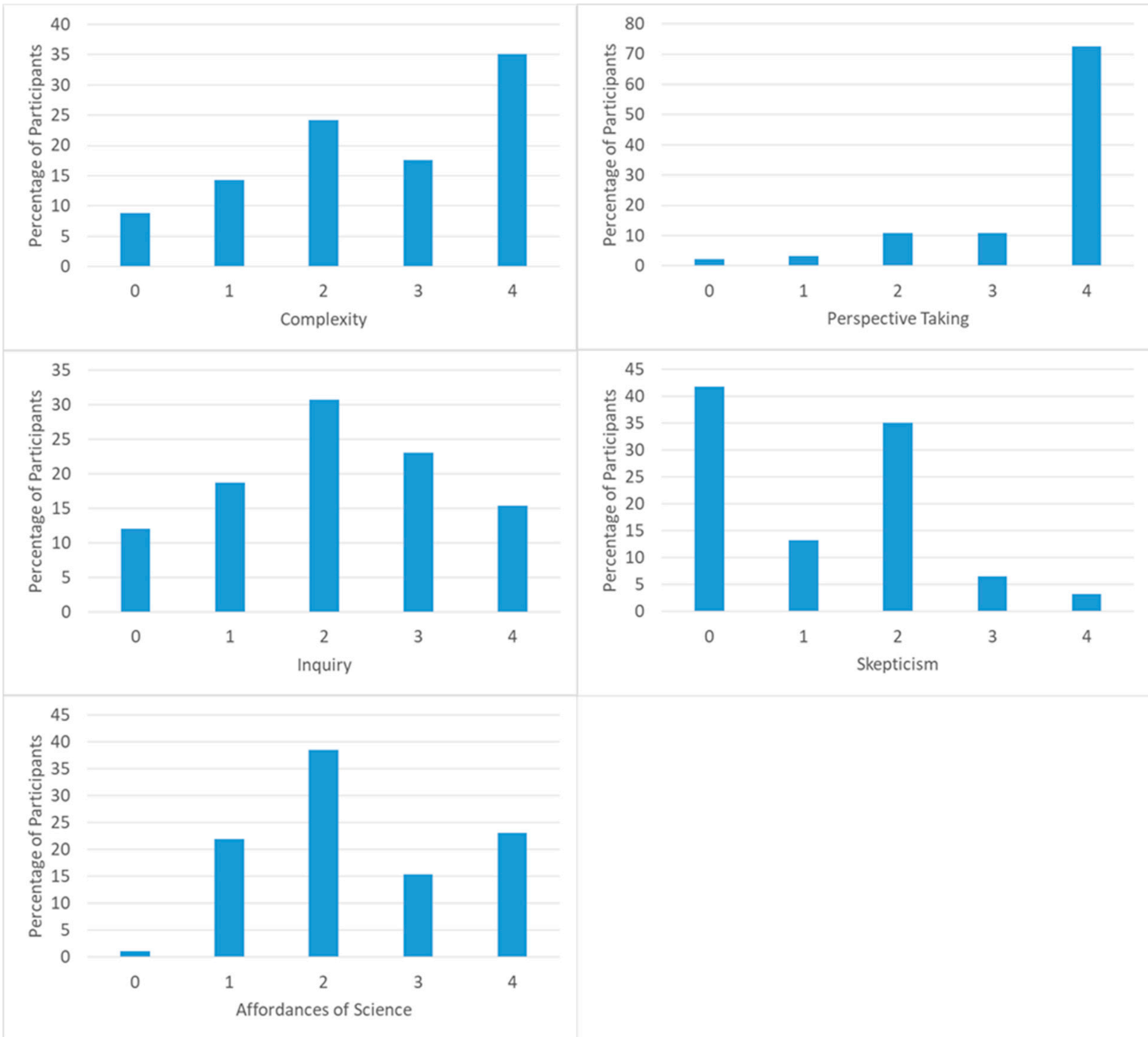

Figure 1. The frequency with which participants exhibited various levels of reasoning across SSR dimensions.

Table 3. Percentage of responses scoring at each level and the mean score for dimensions of SSR.

	Depth of Reasoning					
	0	**1**	**2**	**3**	**4**	**Mean (SD)**
Complexity	9	14	24	18	35	2.6 (1.3)
Perspective Taking	2	3	11	11	73	3.5 (1.0)
Inquiry	12	19	31	23	15	2.1 (1.2)
Skepticism	42	13	35	7	3	1.2 (1.1)
Affordances of Science	1	22	38	15	23	2.4 (1.1)

3.1. Complexity

Participants were prompted to engage in complexity-related SSR by considering whether the RRNI could be solved easily. Non-hydrological sources of reasoning about the complexity of the issue (Table S1) were diverse and generally directed at the complex aspects related to the nature of the problem itself (e.g., economic and political ramifications of the problem, that moral judgements had to be rendered in order to assign responsibility for resolving the problem) or the ways in which human involvement in the issue increased its complexity (e.g., sociologically-related aspects of complexity, such as human ability to understand the problem, and human potential to cooperate in order to resolve the problem). For example, Val exhibited sophisticated reasoning when engaged in complexity-related SSR and touched on a number of non-hydrological aspects of the RRNI that made it difficult to resolve.

> Three different actors are at play: the city, the farmers, and the judicial/governmental system that mitigates these problems. Each one has a stake in this problem, which involves ethics, money, and safety. The city must protect its citizens, the farmers must protect themselves and their families, and the government must ensure it is committed to fairness and equality before the law. Not all of these things can be secured in full, but they can be partially solved, and it is the partiality of satisfaction that makes it so difficult.

Although nearly 10 percent of individuals indicated that the issue would be easy to resolve, the vast majority of participants indicated that the issue would not be easy to solve (Table 3). However, roughly two-thirds failed to provide justification for more than one reasoning source that that made the issue difficult to resolve. This suggests that these undergraduates, as a whole, could use additional practice considering the breath of sources of complexity they identified and developing justifications as to what it was about those sources that contributed to the complexity of the issue and made the issue difficult to resolve.

3.2. Perspective Taking

Participants were prompted to engage in perspective taking regarding the RRNI by considering stakeholder responses (farmers and Des Moines residents) to a proposed resolution to the issue through voluntary conservation measures. Collectively, participants elaborated on a variety of perspectives in their reasoning as to why farmers and Des Moines residents each would and/or would not support the proposed resolution (Table S2). For example, Joanna exhibited sophisticated reasoning when engaged in perspective taking and touched on a number of non-hydrological aspects of the RRNI that would influence the stakeholders' perspectives of a proposed resolution.

> [The farmers] would like the idea because it is voluntary. They want to be able to grow the most yield and so that may mean not being as conscious of the environment. In other words, they do not want to conserve the amount of fertilizers they use if it may have a detrimental effect on crop yield. Since there is no regulation in place, there really isn't a reason they would have to change anything if it impacted them negatively. [The residents of Des Moines] would not like this either as there is no legal ground to the conservation. There is no way to hold farmers accountable if they are not using the fertilizers responsibly, which means if the water is bad nobody takes the blame and the people of Des Moines have to live with the effects.

Like Joanna, the majority of individuals employed reasoning about non-hydrological aspects of stakeholder perspectives that influenced their reaction to the proposed solution to the RRNI, including the economic ramifications of farmers reducing nitrate use or Des Moines Residents upgrading their water treatment facilities, political ramifications of legislating and enforcing regulations, moral judgements in terms of assigning responsibility for resolving the issue, and sociological ramifications of ensuring progress is made toward the health and wellbeing of all involved. Importantly, nearly three-quarters of participants were able to take and justify at least one perspective each of the farmers and of the Des Moines residents (Table 3).

3.3. Inquiry

Participants were prompted to engage in inquiry-related SSR by considering the kinds of additional information that would be necessary for them to make a decision regarding the RRNI. Interestingly, participants engaged in inquiry-related SSR sought information that was hydrological and non-hydrological in nature (Table S3). For example, participants sought hydrologic information about the problem, including the point-source(s) of the nitrate pollution, current nitrate levels, safe nitrate levels, impacts of the problem, and characteristics of the watershed, as well as hydrologic information about the solution (e.g., farming alternatives, precedent regarding how these issues have been solved in the past, treatment/removal of nitrates, a timeframe regarding how long the RRNI will take to solve, and alternative sources of water that Des Moines residents could access). Participants also sought information that was not hydrologic in nature, including economic aspects of the problem and solution, information about the perspectives of the stakeholders involved, political aspects of the issue, effects on human wellbeing, and the potential for human cooperation to lead to a successful resolution. Some participants, such as Phillip, were particularly proficient at employing inquiry-related reasoning that addressed the necessity of both hydrologic and non-hydrologic sources of information that was requisite to their resolving the RRNI.

> I would need to see if each individual farm is releasing too many nitrates into the water or if there a just a few big farms that are causing most of the issues. It would also be helpful to have some information regarding whether or not the city can afford to continue removing the nitrates from the water and whether or not the nitrate concentration is increasing or decreasing. It would also be helpful to know what exactly would be needed on the farmers' part in order to reduce amount of nitrates getting into the river.

Although 10% of individuals indicated that they did not need any additional information, the vast majority of participants (90%) indicated that they needed additional information to make a decision regarding the RRNI (Table 3). As a whole, participants put together an impressive and diverse array of additional sources of scientific and non-scientific information requisite to resolving the issue. However, only 14% of individuals identified multiple sources of necessary information and justified how each would afford the resolution of the issue. Worse, a tenth of participants indicted they did not need additional information, as if the information that the one-page scenario provided was sufficient for solving the RRNI.

3.4. Skepticism

Participants were prompted to engage in skepticism-related SSR by considering whether nitrate levels of water sampled by scientists hired by the farmers and the residents of Des Moines would be similar (Table S4). The vast majority of participants who reasoned that scientists hired by the farmers would find different levels of nitrates than those hired by Des Moines residents attributed the difference to bias related to the scientists' funding source (e.g., scientists purposely hired to provide results favorable to the funder, scientists misrepresenting findings to the benefit of the funder, and/or scientists employing biased methodology, such as non-representative sampling, to the benefit of their funder). One individual employed scientific reasoning and attributed the difference to the error inherent to science practice. Participants who reasoned that the farmers' scientists would find similar levels of nitrate relied on scientific reasoning or an assumption that scientists are unbiased no matter who they are employed by. Participants exhibiting sophisticated skepticism-related SSR, such as Ingrid, included reasoning sources that were hydrological and non-hydrological in nature.

> I think farmer-appointed scientists would not necessarily try to find different levels, but that their testing sites may be different—perhaps there would be a bias towards more upstream locations that have not had time to accumulate as many nitrates, or else at a low point in fertilizer use so that levels read differently. The tests they use could also vary. On the other hand, I would hope the scientists would be ethical enough to try to straight-up replicate the results of the previous set of scientists by using similar methods and similar locations, but you never know.

On average, participants were only able to provide a source of skepticism regarding the scientists' findings without elaborating on how it informed their understanding of the issue or its resolution (Table 3). Although skepticism-related SSR clearly includes reasoning sources that are hydrological and non-hydrological in nature, these undergraduates struggled to justify their importance to the RRNI.

3.5. Affordances of Science

Participants were prompted to reason about the affordances of science dimension of SSR by considering ways that scientists could contribute to the resolution of the RRNI (Table S5). All participants provided at least one contribution that science could make to the resolution of the RRNI (Table 3), the bulk of whom provided hydrologically oriented contributions to the resolution of the RRNI by way of engagement in science practices that included communicating information, investigating problems, developing solutions, monitoring the situation, and/or providing a perspective that was unbiased. Kendra was one participant who exhibited sophisticated affordances of science-related SSR while touching on hydrological and non-hydrological (e.g., ethical) aspects of the RRNI.

> I think that the general unbiased, exact, and straightforward information and results given by the scientists on both sides would lead to the answer. If the results show a huge issue with the nitrates from both sides findings, then we know some change needs to happen. Vice versa, if both sides findings show little nitrate issue, then possibly there was a fuss for no reason, and if the findings conclude an obvious issue but something that is not pressing, then maybe more research and work can be done over an extended period of time to find a solution.

That no individuals indicated that science could not contribute to the resolution of the RRNI is a promising finding; however, little more than a fifth of participants identified with justification multiple means by which science contributes to a greater understanding of the RRNI and potential resolution. Clearly, water-literate individuals should be able to consider and justify the contribution of different science practices toward the resolution of any SHI. Furthermore, courses designed to facilitate the development of such literacy should engage students in the entire bevy of science practices, including developing students' understanding of their real-world import, so that these individuals are able to understand and relate the importance of each science practice toward their contribution to resolving contemporary SHI.

4. Discussion

As the socio-hydrological challenges of today and tomorrow within the food–energy–water nexus intensify [1–3], it is essential to prepare future decision-makers with the reasoning tools necessary to make effective decisions based on scientific understanding [21]. This ability to take perspectives and weigh decisions in manner that includes and addresses hydrological and non-hydrological aspects of

SHI is an essential part of water literacy [15,16]. Nonetheless, prior research has shown that students, and adults, struggle to understand water-related concepts [14,22–26]. Water does, and will continue to, affect human and natural systems [8], and therefore it will continue to be a critical focus of science teaching and learning across the K-16 continuum [9,10]. For this reason, education reform at the postsecondary level focused on preparing individuals to confront and resolve hydrological challenges remains a priority [52].

Although the demand for research that illuminates the potential for undergraduate courses that do so is high, few studies have explored the development of SSR in the context of SHI. In doing so, this study builds upon and contributes to prior research on teaching and learning about natural and managed water systems, particularly in undergraduate STEM [11–13,19,20,52,53] and non-STEM [54,55] contexts, where new courses that employ innovative, effective approaches to exploring challenges regarding water resource use and management are emerging (e.g., [2,12,13,19,48,56–59]. Additionally, the findings herein contribute to the broader literature base focused on SSI teaching and learning, where SSI have served as viable contexts for the development of science content knowledge and practice skills (e.g., [31,32], as well as habits of mind and reasoning skills, such as perspective taking and exhibiting skepticism when confronted with various media [39], that are not scientific in nature, but equally important to the development of informed resolutions [17,48,60–63]. Specifically, the results reported herein provide evidence for undergraduate students' exhibiting varying degrees of SSR sophistication through consideration of SHI.

First, we found SHI to serve as a meaningful context for undergraduates' development of functional water literacy through engagement in SSR. More specifically, the RRNI served as a meaningful context for undergraduates to reason about hydrological (e.g., communicating about SHI, investigating SHI, developing solutions to SHI, and monitoring SHI) and non-hydrological (e.g., economic and political ramifications of the SHI and its resolution, moral judgements related to assigning responsibility, ethics related to bias in science, and sociological aspects of promoting human progress, well-being, and cooperation, etc.) factors that often accompany SHI. Additionally, a number of students exhibited sophisticated reasoning about the RRNI through the different dimensions of SSR. However, sophistication varied both within and between the dimensions of SSR, and a number of students' SSR was highly limited, which suggests that work remains to be done in the development of courses that contribute to students' water literacy. For example, while a third of students exhibited sophisticated reasoning about the complexity of the issue, nearly 10% indicated it could be easily solved. Similarly, participants overwhelmingly were able to recognize the potential for bias to affect scientists' finding according to their funders, but few recognized the potential that variation in nitrate levels might happen naturally over time, or that error inherent to scientific practice could account for varied findings, which may indicate nature of scientific misunderstanding in the context of the RRNI [33,64]. Although three-quarters of participants were able take the perspective of both stakeholders, few indicated with justification additional information sources necessary for resolving the issue. These findings suggest that even after completing a course directed at understanding and resolving SHI, undergraduates still struggled with recognizing the various aspects of the SHI that contribute to its ill-defined nature and the ongoing inquiry necessary for informed consideration and resolution of SHI.

Second, the insights afforded here as to how students engage in different dimensions of SSR have implications for the facilitation of instruction that directly supports student development in each dimension of SSR. For example, due to the multifaceted and often-contentious nature of SSI and the diverse viewpoints of stakeholders they impact, individuals are likely to construe SSI differently and offer various ideas and solutions that may be contradictory but equally plausible [65]. For this reason, students' conceptions of the complexity of SSI, of the perspectives that stakeholders may espouse regarding them, and of additional information necessary for their resolution may vary considerably. Importantly however, the reasoning that students employ and the perspectives they take must be justifiable [7]. Instructors looking to enhance their students' SSR in these dimensions (i.e., complexity, perspective taking, and inquiry) can do so by taking advantage of the collective ability of the individuals comprising their classrooms, where a number of perspectives are available, valuable, and informative. As a community of learners develops around the consideration and resolution of SHI, their ideas and the resources they access in the context of an issue afford opportunities for learning in that environment [30], and the breadth of participants' collective SSR serve as a meaningful starting point for increasing the depth of their reasoning. As sources of reasoning supplied by students are collated, instructors can ask questions, such as ''how does this or that source of reasoning make the issue more difficult to resolve?" or ''how is this piece of information critical to resolving this issue?". Similarly, the diversity of perspectives that are expressed by students both within and between stakeholder groups serves as fodder for discussion when debriefing student reasoning about stakeholder perspectives and seeking to justify their accuracy [66]. That said, instructors need not reject the potential of students' under-sophisticated offerings regarding these dimensions of SSR. Rather, instructors can respect and even validate their students' responses by using them as a starting point for elaborating on or justifying their importance to understanding or resolving the SHI on one hand, or discarding them if their justification is not feasible.

5. Implications

These findings have implications for the facilitation of instruction meant to bolster students' SSR regarding skepticism about potentially biased sources of information and about that which science affords to the understanding and resolution of SHI. Individuals exhibiting sophisticated SSR consider the trustworthiness of SHI information sources (i.e., skepticism; [67]), and although science alone cannot resolve SSI [4,15], recognize that scientific knowledge and the practices that generate it significantly contribute to our ability to resolve SHI (i.e., affordances of science, [16]). Previous studies suggest that undergraduates' nature of science and science practice skills are weak upon arriving at college [68,69]. These findings go a step further by suggesting undergraduates are unable to situate a nature-of-science understanding in the context of SSI, considering that understanding of any issue or phenomenon is constrained by human capacity to accurately measure and account for phenomena, nor are they able to recognize how science practices allow one to better understand and respond to SHI. Thus, courses designed for the purpose of enhancing functional water literacy [17,18] need to include explicit instruction as to the nature of science, especially with regard to SHI information sources [70], and engage students in science practices in the context of resolving SHI while making explicit how those science practices afford an understanding of the issue and potential resolutions, as well as where science is limited in doing so. In sum, these implications for instruction suggest that with appropriate support, teachers should be able to significantly enhance their students exhibited SSR through targeted instruction toward the different dimensions of SSR.

Additionally, this study has implications for operationalizing, measuring, and describing undergraduate students' SSR, as well as for supporting its development for use in research as well as in the classroom. Assessments, such as QuASSR, can aid instructors seeking to enhance students' SSR, and consideration of the breadth of reasoning sources to which students refer and depth of the SSR they exhibit in justifying those sources in the context of any SHI should serve to guide their development of functional water literacy. The reasoning sources to which students collectively refer can serve as a starting point from which instructors can aid their students in developing justifications as to their relevance to the problem and potential solutions. Once students have effectively justified those sources that were important and disregarded those they were not able to justify, they can return to the QuASSR scenario, and their newly informed responses can be scored using the rubric to determine whether the plethora of sources previously provided were effectively justified, and thus, their SSR enhanced. This should serve as a means for scaffolding students' development of SSR, while illuminating the diversity of perspectives and considerations that contribute to each of their peer's understanding and resolution of SHI. Of course, future courses directed at understanding and addressing challenges related to water resource use and management need continue to develop content knowledge [14,22,55], but must provide ample opportunity for undergraduates to incorporate their scientific understanding into position-taking and decision-making about SHI by addressing non-science considerations. Postsecondary instructors looking to implement instruction in the context of SHI should task students with considering and evaluating the means by which others reason about similar issues to better inform the collective and aid their taking of perspectives, exhibiting of empathy, and having of conversations to overcome stated challenges, thus contributing to the strength of civil society.

Finally, these findings have implications for the design of undergraduate courses focused on supporting students' functional water literacy. These findings provide evidence that SHI serve as viable contexts for undergraduates to reason about hydrological and non-hydrological aspects of water-related issues, both of which are requisite to functional water literacy. As such, they add to a growing body of evidence indicating that SSI serve as viable contexts for learning and practicing science [31–36]. However, it is worth noting that the results herein focusing on SSR are purely descriptive, based upon a single student task during the semester. Future work should explore changes in students' SSR over time, whether during a single semester or over longer-term, programmatic timelines. Additionally, as contexts in which learning is situated afford and constrain the development of understanding [30], these findings are bound to participants in a single water-literacy course reasoning about one socio-hydrological issue, the RRNI. It is not clear how the sophistication of reasoning might differ among a different set of individuals in a different region and in the context of a different socio-hydrological issue. Future studies might begin to consider which sources of SSR dimensions are most supported and how media, family, and culture in general may influence which sources students lean on more heavily than others and how that affects those students' potential for arguing effectively. Given that an understanding of STEM alone is insufficient for resolving many of the world's most pressing issues [4,5], undergraduate courses must go further than procuring the development of socio-hydrological understanding about issues and better lend themselves to students' development of SSR and its integration with the desired content knowledge in the context of resolving SHI.

6. Conclusions

In an increasingly globalized community confronted with an array of socio-scientific challenges, it is essential to understand undergraduates' SSR and how it can be fostered in classrooms which, for many postsecondary students, may be the last science learning experience they have in a formal learning setting. The charge for undergraduate instructors is to cultivate students' scientific literacy, particularly about socio-hydrological systems, which reflect the complex, multifaceted, interconnected nature of contemporary SHI [40]. Educators must work to ensure that today's undergraduates—both STEM and non-STEM majors—who are tomorrow's global citizens, have access to an education that emphasizes the importance of science-informed reasoning and decision-making. This study, as well as the institutional and course context in which it is embedded, provide insight into strategies and outcomes associated with innovative, interdisciplinary undergraduate teaching and learning about water [2,71] in the context of SHI. We found SHI to hold great potential as meaningful contexts for the development of water literacy, and that SSR is a viable and useful construct for better understanding undergraduates' reasoning about the hydrological and non-hydrological aspects of SHI. Undergraduate courses, such as the one described in this study, can be designed to support students' development of content knowledge and reasoning skills that enable them to engage with the most pressing challenges of the Anthropocene, and the SSR construct serves as a viable means for doing so.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/10/2857/s1, Table S1: Raccoon River Nitrates Issue QuASSR, Table S2: Depth of SSR Rubric, Table S3: Depth of SSR Exemplars with QuASSR Rubric.

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Appendix A

Table A1. Depth of SSR rubric.

Lvl	Complexity	Perspective Taking	Inquiry	Skepticism	Affordance of Science
0	Suggests that the issue is not complex or provides an illogical response.	Presents perspectives that are not consistent with stakeholder views.	Suggests that no further inquiry is required or provides an illogical response.	Suggests that the reports would be similar or provides an illogical response.	Suggests that science would not be helpful or provides an illogical response.
1	Identifies at least one source of complexity.	Presents a perspective consistent with a stakeholder view.	Identifies an area of further inquiry.	Identifies one way in which the reports would be different.	Identifies one way in which science would be helpful for issue resolution.
2	Identifies at least one source of complexity, and provides a contextual explanation or justification of a source.	Presents a perspective consistent with a stakeholder view, and provides a contextual explanation, justification, or elaboration of the perspective.	Identifies at least one area of further inquiry, and provides a contextual explanation, justification, or description of an area of inquiry.	Identifies one way in which the reports would be different, and provides an explanation or justification for the difference.	Identifies one way in which science would be helpful, and provides an explanation or justification.
3	Identifies at least two sources of complexity, and provides a contextual explanation or justification for one of those sources.	Presents perspectives consistent with both stakeholder views, and provides a contextual explanation, justification, or elaboration of one of those perspectives.	Identifies at least two areas of further inquiry, and provides contextual explanation, justification, or description for one of those areas.	Identifies two ways in which the reports would be different, and provides an explanation or justification for one difference.	Identifies two ways in which science would be helpful, and provides an explanation or justification for one.
4	Identifies two or more sources of complexity, and provides contextual explanations or justifications for at least two of those sources.	Presents perspectives consistent with both stakeholder views, and provides a contextual explanation, justification, or elaboration of both perspectives.	Identifies two or more areas of inquiry, and provides contextual explanation/justification/description for at least two of those areas.	Identifies two ways in which the reports would be different, and provides an explanation or justification for both differences.	Identifies two ways in which science would be helpful, and provides an explanation or justification for both.

The rubric was used to score each participant's response to the five-item item Racoon River Nitrates Issue (RRNI) Quantitative Assessment of Socio-Scientific Reasoning (QuASSR), each relating to one of the five five dimensions of SSR. These scores served to indicate the depth of SSR exhibited.

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