Undergraduate Students' Scientifically Informed Decision Making About Socio-Hydrological Issues

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Although knowledge of disciplinary concepts and epistemic understanding of science are foundations of scientific literacy, students must learn to apply their knowledge to real-world situations. To engage effectively with contemporary water-related challenges with scientific and social dimensions, students need to understand the properties of water and the nature of scientific processes and practices. However, students have difficulty in understanding core hydrologic concepts, and more work is needed to determine how they structure their decision making about socio-hydrological issues. In this study, we investigated undergraduate students' decision making with a focus on the resources they leveraged to make and support their decisions about socio-hydrological issues. We show that students (a) more effectively articulated a decision than provided support for their decision, (b) typically either included both statements of scientific information and rationale for their opinions within their decision or included neither, and (c) have difficulty transferring the decision-making framework to a voting scenario. Findings provide insight into the development of scientific literacy and engagement with decision making about socio-hydrological issues among undergraduate students.

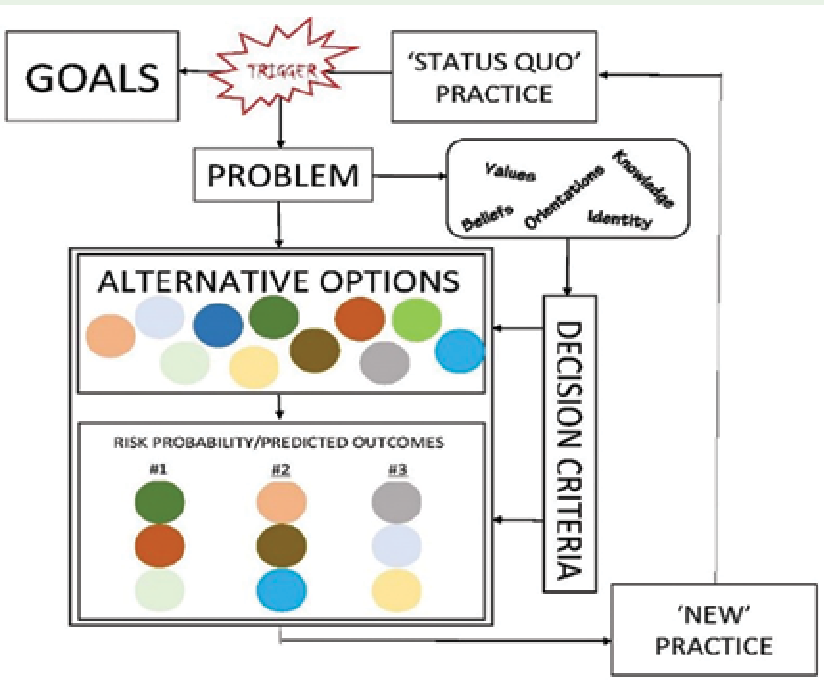
Contemporary societies face an array of global challenges, such as population growth, food production, natural resource use, and environmental degradation. These kinds of socio-scientific issues (SSIs), or global challenges with both scientific and social dimensions, provide a strong rationale for the importance of an emphasis on systemic science education efforts aimed at cultivating a scientifically literate populous. This includes a focus at the postsecondary level (National Research Council [NRC], 2012), where recent research has suggested that first-year students possess only slightly higher levels of science literacy than the general public and that gains in science literacy among undergraduate students are modest (Impey, Buxner, Antonellis, Johnson, & King, 2011). Knowledge of scientific concepts is a foundation of scientific literacy but it is important to note that students must also learn to use or apply this knowledge in context. Science literacy has been defined in many ways and was recently described as including the ability to engage in civic decisions around science-related issues (National Academies of Sciences, Engineering, & Medicine, 2016). We follow this definition, contemporary science literacy perspectives (e.g., Bybee, McCrae, & Laurie, 2009; Feinstein, 2010; Rudolph, 2014), and work from the decision sciences (Arvai, Campbell, Baird, & Rivers, 2004) to justify a focus on science literacy learning goals particularly around decision making. We define these goals as an enhanced capacity, both at the individual and collective levels, to make effective decisions grounded in STEM-informed analyses of complex, real-world challenges.

The 21st century has been referred to as the "water century" because "ensuring an adequate quantity and quality of freshwater for sustaining all forms of life is a growing challenge" (National Science Foundation Advisory Committee for Environmental Research and Education, 2005, p. 6). This makes socio-hydrological issues, or water-focused SSIs, critical to questions of water resource use and management. To make decisions about how and by whom water should be used, individuals must confront the social, economic, legal, and political dimensions of socio-hydrological issues, as well as their scientific dimensions. Innovative approaches have been developed to engage undergraduate students in becoming informed about water issues including courses focused on water science (e.g., Thompson, Ngambeki, Troch, Sivapalan, & Evangelou, 2012), hydrology education (e.g., King, O'Donnell, & Caylor, 2012), and environmental stewardship (Tolley, Everham, McDonald, & Savarese, 2002). However, research has illustrated gaps in students' knowledge of core hydrologic concepts across the K–16 continuum (Covitt, Gunckel, & Anderson, 2009; Forbes, Zangori, & Schwarz, 2015; Halvorson & Wescoat, 2002). STEM (science, technology, engineering, and mathematics) and non-STEM high school and college students have also been found to experience challenges in making science-informed decisions about complex issues, including focusing on personal relevance or values as opposed to contemplation of scientific evidence (Hong & Chang, 2004; Sadler, Chambers, & Zeidler, 2004) and struggling to integrate knowledge gained in science with real-world problems (Kolsto, 2001, 2006). Overall, less work has been done on core challenges facing students in terms of decision making in the context of water issues and the competencies that will allow them to apply disciplinary knowledge to develop science literacy about water issues (e.g., Eisen, Hall, Lee, & Zupko, 2009; Gupta, 2005; King et al., 2012; Kosal, Lawrence, & Austin, 2010; Smith, Edwards, & Raschke, 2006; Willerment et al., 2013; Williams, Lansey, & Washburne, 2009). Therefore, more work is needed to understand how to better support undergraduate students in developing science literacy in the context of specific content topics, particularly in learning to engage in decision making about issues so they can make informed decisions as tomorrow's global citizens.

To begin to address this gap in the literature, we designed and investigated a novel approach to engaging students in decision making about socio-hydrological issues. We developed a multicriteria decision-making (MCDM; Majumder, 2015) framework (Figure 1) drawn from work and learning theory on how students make decisions within the decision sciences (e.g., Arvai et al., 2004; Hammond, Keeney, & Raiffa, 2015) and the STEM education community (e.g., Halverson, Siegel, & Freyermuth, 2009; Sadler, & Zeidler, 2005). This framework served as the foundation for an undergraduate introductory course focused on supporting students in making decisions about real-world issues regarding food, energy, and water systems (Dauer & Forbes, 2016; Dauer, Lute, & Straka, 2017). This framework illustrates that high-quality decisions involve weighing multiple options based on a complex set of interacting criteria and accounts for how decisions about complex issues with many interrelated dimensions are made over periods of time. The course engaged students in particular real-world issues and then supported their ability to make high-quality decisions by weighing several options, applying relevant scientific information to determine consequences of each option, and examining their own values to make a clear and consistent decision about the issue. In this study, we examined the factors that contributed to undergraduate students' decisions about socio-hydrological issues in the course unit focused on water and water uses as they engaged in this newly

FIGURE 1

Generalized model of multicriteria decision making (MCDM).



developed course and framework. Specifically, we asked:

- What aspects of the decision-making process were students able to engage in most effectively when they considered socio-hydrological issues?
- In what ways do students' decisions about socio-hydrological issues with higher scores differ from students' decisions with lower scores?
- What factors or resources do students use to make and support their decision about voting on a socio-hydrological issue?

Study design and methods

Context and participants

This mixed methods study involved both STEM and non-STEM undergraduate students (n = 198), primarily first-year college students enrolled in a required, introductory course focused on contemporary food, energy, and water issues at a large Midwestern university (for a thorough description of the course, see Dauer & Forbes, 2016 and Dauer et al., 2017). Students participated in active-learning lecture; small-group discussions; assignments to evaluate claims, evidence, and trustworthiness of popular media articles; and activities to support students' use of values and scientific information in their opinions about an issue. The focus of this study was on the course's water unit.

Data collection

Students completed an assignment focused on a specific socio-hydrological issue: the use of groundwater for agricultural irrigation. Students were asked to read two popular media articles and one science research article focused on the use of water for agricultural irrigation and then answer a series of questions:

1. Write a one-sentence statement of what you value that is relevant to this issue. Explain how it is relevant.
2. Using both your statement of value and the scientific information in the articles you've read or we've discussed in class, answer the following: What is your opinion about whether or not we should restrict the amount of water used for agricultural irrigation in [our state]? Why?
3. What would someone who disagrees with you say about whether or not we should restrict the amount of water used for agricultural irrigation in [our state]?
4. How would you address these arguments from someone who disagrees with you? Identify the best counterargument.

Students received a grade for the assignment using a different set of evaluation criteria than used to analyze the assignments for the present study. Although students were asked about their values, an analysis of those values and how they affected students' decisions is beyond the scope of this study. The focus of this study was primarily on the decision itself (Assignment Question 2) and on the consistency and support for the decision over all four assignment questions.

Fifteen students also participated in semistructured interviews (Merriam, 2009) after they completed the assignment. These interviews ranged from 45 to 65 minutes and focused on students' content knowledge about water, developing knowledge about classroom topics and artifacts, and opinions and decision making about water resource management. At the end of each interview, students were asked to vote in a fictional scenario. This scenario involved the state placing an additional tax on all landowners to create revenue to fund incentives for farmers to adopt technology that would make irrigation more efficient and use less water. Students were asked if they would have voted for or against the action and why. The interviews were audio-recorded and transcribed for analysis.

Data analysis

On the basis of the theory and research regarding decision making (Arvai et al., 2004; Christenson & Chang Rundgren, 2015), we developed a rubric to score the decision-making aspects of the written assignments. Each dimension was scored on a 4-point scale ranging from 0 to 3. Rubric Item 1(R1) examined the *decision* students were asked to make regarding the issue of restricting the amount of water used for agricultural irrigation. Rubric Item 2 (R2) examined the *scientific information* students included for both correctness and relevance. Rubric Item 3 (R3) examined the *rationale for opinions* students included and focused on the degree to which they included reasoning to support their opinions. Rubric Item 4 (R4) examined the *consistency* in the decision and support throughout all the assignment answers. We established interrater agreement between two coders by coding a 10% sample of the assignments (n = 20). Interrater agreement was approximately 73% before discussion and 100% following discussion. The rubric is included in Appendix A (available online at http://www.nsta.org/college/connections.aspx).

We analyzed the scores on the individual rubric items using descriptive statistics to examine relationships among the scores. We then qualitatively examined student responses that fell into each of the rubric categories. The analysis of these scores consisted of identification of themes that emerged from within each of the scoring groups. Themes from the highest and lowest scorers are presented here. Finally, we used qualitative analysis to examine students' responses within the interviews. Transcribed interviews were imported into a qualitative analysis tool (MaxQDA) and coded with a priori codes of making decisions, forming opinions, using/seeking scientific information, and voting rationale. Examples of each of these codes are included in Appendix B (available online at http://www.nsta.org/college/connections.aspx). We then identified the emergent themes presented in the findings.

Results

In Research Question 1, we asked, "What aspects of the decision-making process were students able to engage in most effectively when they considered socio-hydrological issues?" Results indicated that on the written assignment, students (*n* = 198) achieved higher scores, on average, for clearly articulating an overall decision than they did for including scientific information or supporting rationale for their opinions (Figure 2). As indicated by the mode of Rubric Item 1 (R1; Table 1), more students posed a clearly defined decision with strongly aligning support and no contradictions than students who did not. However, as indicated by the mode of R2 (Table 1), students infrequently included correct and relevant statements of scientific information throughout the decision.

Students scored higher on stating an overall decision than they did on any of the other rubric items: The mean score for R1 (overall decision) was higher than for R2 (scientific information), R3 (rationale for opinions), and R4 (consistency; Table 1). However, the scores for students' inclusion of scientific information (R2) and supporting rationale for their opinions (R3) were similar. This indicates students were either as likely to include support for their opinions as they were likely to include scientific information, or they were similarly likely to include neither. This is explored further in the second research question. Overall, these results suggest that students were more effective at stating a decision than they were in providing support and rationale, either factual or opinion, for that decision.

FIGURE 2

Rubric item descriptive statistics on students' (*n* = 198) written assignments.

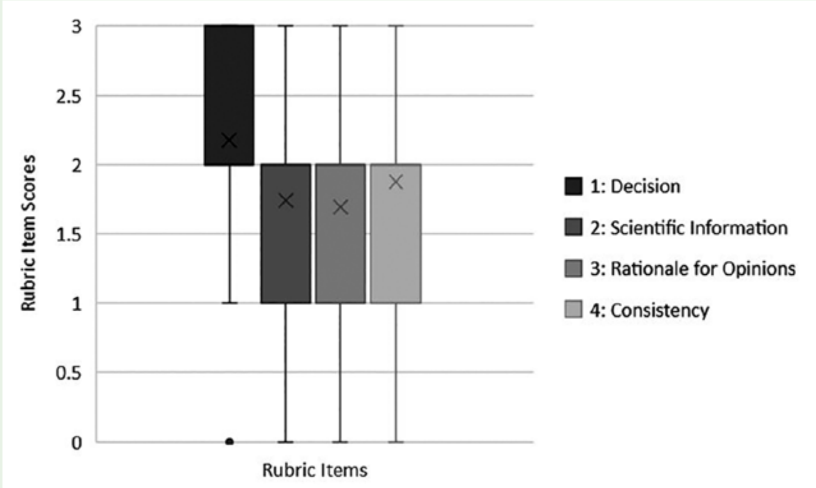


TABLE 1

Rubric item descriptive statistics.

Rubric item	*M*	Mode	*SD*	Obtained score range
R1 (overall decision)	2.18	3	0.06	0–3
R2 (scientific information)	1.74	2	0.06	0–3
R3 (rationale)	1.69	2	0.06	0–3
R4 (consistency)	1.87	2	0.05	0–3

In Research Question 2, we asked, "In what ways do students' decisions about socio-hydrological issues with higher scores differ from students' decisions with lower scores?" Results of qualitative analyses suggest students with higher scores across rubric items tended to state clear, explicit decisions and to incorporate support for their positions throughout their answers. For example, a student who achieved a score of 3 on all components of the rubric wrote the following for his decision:

> We should limit water usage to an amount that allows farmers to still remain profitable, but also allows the aquifer to be recharged in certain areas. This allows for the economic growth of the region, while providing a feasible way to ensure a water resource for future generations. (218_Water assignment)

In this example, the student stated a clear decision to limit water usage and provided reasoning for the decision. Both in his decision statement and later when he discussed a counterargument to an opposing view, this student included factual, scientific information statements that aligned with information from the articles he had read and provided support for the opinion statements he wrote. These aspects are evident in his response to a person with an opposing view:

> I would respond to this person by stating that it has been shown that corn could use less water and still be profitable. Also, I would attempt to offer other crops that could be grown with less water and still be just as profitable. The main argument for this would be that if this type of withdrawal and irrigation method continues, the water may be gone two to three generations from now. (218_Water assignment)

This representative example shows that students with higher scores incorporated scientific information and reasoning to support the decisions they made about water-based SSIs.

Students with lower scores tended to have much shorter answers and typically did not include as much, or any, support for their statements. A student with a low average overall score (0.8) achieved a score of 0 on R1 (overall decision) and a score of 1 on all other rubric items. In her decision statement, the student did not provide a clear decision regarding whether to restrict the amount of water used for irrigation purposes. She said:

> I don't know if it is possible to restrict farmers from using a certain amount of water because they are ultimately going to take whatever they need to make money but if they were restricted there would have to be strict rules and guidelines in place to enforce the farmers. (306_Water assignment)

This student included only very limited factual statements of scientific information by indicating that irrigation of crops leads to production for food consumption: "They are using a substantial amount of water but they are using it to irrigate their crops, which in turn you [can] eat because of it" (306_Water assignment). Further, she included very little reasoning to support her opinion statements. For example, in her value statement she said, "I value that future generations also need to use these same water sources so we cannot deplete everything now" (306_Water assignment). As opposed to the students with higher scores, students with lower scores tended to rely on opinion statements and little scientific information to support their decision about water-based SSIs.

The findings in this research question further inform those from the first research question concerning the low scores for students' inclusion of scientific information and rationale for opinion statements. Here we have shown that students with higher scores overall typically included both scientific information and rationale for their opinion statements, whereas those with lower overall scores typically did not include any substantive support for their decisions. The similar rubric scores between statements focused on scientific information and those focused on supporting rationale for opinions indicate that students included both types of statements to a similar degree. Overall, this indicates that (a) students with clearly defined decisions were more likely to include support for their decisions, and (b) when students included support, they typically included both scientific information and rationale for the opinions. However, if students did not include one of these, they typically also did not include the other.

In Research Question 3, we asked, "What factors or resources do students use to make and support their decision about voting on a socio-hydrological issue?" Qualitative analysis of interview data (n = 15) indicates that although some students included both scientific information and rationale for their opinions when they made decisions as a part of the assignment, students largely did not include robust rationale when asked to step slightly outside the assignment topic to make a decision regarding voting on that issue. When students were given a realistic voting scenario in which they were asked to make a decision about raising taxes to fund irrigation technology for farmers, they typically supported their decision with broad and vague claims, even when they had included more specific rationale when they discussed their decision from the assignment. For example, discussing her decision in the assignment, one student said:

> I think we should [restrict water for irrigation] because we rely a lot on this Ogallala aquifer and it seems that our population is just growing and growing and we need to find a way that we can all still live off of it without depleting it. There's more people coming in, it would just be natural to have each person use less as compared to . . . if there's only one person using the Ogallala aquifer, yes, they could use as much as they want. Now, there's like hundreds, thousands of people who are using it, so now, we just cut back on each person who's using it so that way, we can all get some water from it. (Water Student II)

However, when asked about the voting scenario, she included much less support for her decision:

> I would vote for it. I think that our tax money would be going to a pretty good cause then. That seems like a dream come true with some more effective way of irrigating and it uses less water, so, yes I'll go and vote for that. (Water_Student II)

In a second example, another student provided limited rationale both for the decision he made regarding the topic in the assignment and in the voting scenario. Speaking about the assignment, he said:

> Yes, I would say yes we should restrict water for agriculture. Because water is a natural resource but also good quality water is not unlimited. We only have so much of it so we should try to conserve what we have. (Water_Student TT)

Although he did provide some support for his decision, it is in broad terms and does not consider many aspects of the problem. The same was then true when he spoke about the voting scenario. When asked whether he would vote for the tax to fund irrigation technology, he said:

> I would vote yes for that tax. This would get farmers and companies looking for new ways to use less groundwater and it would get things going. So like, I know the farmers wouldn't like it one bit. You know. We do need to preserve the water; we should start now. So I would have voted yes. (Water_Student TT)

These broad claims lacked explanation as to why students believed them, even when prompted by the interviewer. Further, none of the interviewed students included scientific information they had obtained from the articles or class to support their ideas regarding voting. Although some students chose to include scientific information from the articles when they discussed the issues generally and when they discussed their original decision in the interviews, they did not include them in their discussion of decisions that had the potential to have real impact, such as a vote for funding.

Discussion

In this study, we address the need for understanding how undergraduate students structure their decision making about socio-hydrological issues. The study is grounded in and informs research on students' understanding of hydrological concepts (e.g., Forbes et al., 2015; Covitt et al., 2009; Halvorson & Wescoat, 2002), science literacy (e.g., Bybee et al., 2009; Feinstein, 2010; Impey et al., 2011; Rudolph, 2014), decision science (e.g., Arvai et al., 2004; Hammond et al., 2015; Majumder, 2015), and SSIs (e.g., Halverson et al., 2009; Sadler & Zeidler, 2005). These scientific concepts, processes, and practices are an important focus for postsecondary students to advance scientific literacy among citizens (NRC, 2012). Here, we contribute to this body of work by illustrating the aspects of decision making on which undergraduate students focus and the effectiveness of the various aspects of their decision making.

First, this study shows that students more effectively form a clear and consistent decision than support their decision with accurate scientific information statements or provide support for their opinion statements. Although most students were able to state a clear decision, they were not as successful at providing support for that decision with factual scientific information or at providing rationale for opinion statements they included as support. Second, students who provided clear, explicit decisions were more likely to incorporate appropriate support for the positions as opposed to students with shorter, less explicit decisions who typically did not include substantive support. Students with longer and more explicit decisions were more likely to include both scientific information and rationale for their opinions as support for their decisions, whereas students with less explicit decisions typically included neither scientific information nor rationale for their opinions to support for their decision. Third, although some of the students included scientific information and rationale to support their opinions as part of their decisions in the assignments, this was not the case for the interviewed students when asked to make a decision regarding voting on the issue. Students typically included very limited to no support and made vague and broad claims when they explained why they would vote for or against a tax increase. Although past work has focused on the perspectives students rely on when they make decisions (Halverson et al., 2009) or focused on particular content knowledge needed for decision making (Sadler & Ziedler, 2005), these findings contribute to the field by examining how students engaged in decision making within a particular framework and, specifically, the factors students considered and the extent to which they supported the decision they made.

Taken together, these results suggest that students need additional instruction on the importance of providing supporting scientific information and rationale to strengthen their decision statements. Because students typically included either both statements of scientific information and rationale for opinions or did not include either, this also suggests that some students may need additional support to consider the scientific information that would support their decision and to provide sufficient rationale for opinion statements. Some students may also need support to learn how to more effectively incorporate both scientific information and rationale for opinions into their decisions once they have identified those supporting criteria. The decision-sciences support the notion that the *process* by which the decision is made defines a quality decision, and that a key component of that process is applying scientific and technical details to understand the consequences of potential solutions to a problem (Wilson & Arvai, 2006). To support this process in the classroom, additional structure, such as specific steps of decision making, could be incorporated into existing instructional models to support students as they learn to engage in all of these aspects of forming and supporting a decision (see Dauer & Forbes, 2016; Dauer et al. 2017). Though some approaches to exploring the challenges surrounding water resource use and management have been addressed through courses at the undergraduate level (e.g., Eisen et al., 2009; Gupta, 2005; King et al., 2012; Kosal et al., 2010; Smith et al., 2006; Thompson et al., 2012; Tolley et al., 2002; Willerment et al., 2013; Williams et al., 2009), these types of courses and curriculum are not widespread. Future work should focus on developing more of these types of courses that will engage and support students in considering the various aspects of SSIs, making effective decisions, supporting those decisions with scientific information and rationale, and reaching science literacy.

Finally, though some students were successful at incorporating support into their decisions on the assignments, overall they had difficulty in applying the decision-making framework to a slightly different, less-structured scenario. This indicates that students may have difficulty *transferring* the decision-making process from a class setting to the real-world scenarios they will encounter as voting citizens. To address this issue, undergraduate courses should provide a more direct emphasis on decision making as a normal part of instruction, in addition to the existing focus on scientific content. Courses should continue to focus on improving knowledge of core hydrologic concepts (Covitt et al., 2009; Forbes et al., 2015; Halvorson & Wescoat, 2002), but should also support students to make choices based on scientific evidence rather than only on personal relevance (Hong & Change, 2004; Sadler et al., 2004) and to integrate scientific knowledge into real-world problems (Kolsto, 2001, 2006). Providing students with opportunities to make decisions regarding the content they are learning in science courses is particularly important to improve the scientific literacy gains beyond the 10%–15% recently documented among graduating students (Impey et al., 2011). Additional course design and research should focus on the best ways to support undergraduate students in engaging in contemporary SSIs so that they can learn to make informed decisions they will encounter as global citizens.

These findings have important

implications for structuring interdisciplinary STEM learning environments that will effectively engage students in SSIs and support them to incorporate rationale and scientific information into the decisions they make both in the classroom and beyond. This study was part of the first iteration of a novel course focused specifically on supporting students to engage in socio-scientific decision making (Dauer & Forbes, 2016), but students still had some difficulties in the process even within that context. The course has continued to evolve and ongoing efforts focus on refining the decision-making framework and learning opportunities for students. Study findings help identify areas in which students can benefit from additional support when learning to use information effectively to make decisions about water-related issues. Although the focus of this study was on socio-hydrological issues, the implications for these findings may extend beyond water-related issues and are applicable to supporting students in learning to consider and make decisions about SSIs, in general. These findings also have the potential to inform expert-novice research and future work could explore how students develop their decision-making skills over time and the conditions that best support those who become more skilled at decision making. Findings from this work provide important insight into undergraduate students' development of scientific literacy as well as their engagement with decision making about SSIs. As a result, this study adds to the existing literature by offering a framework by which students can learn to engage in decision making as well as preliminary analysis of how introductory students consider decision making about SSIs as a foundation for more work to advance these skills and further refine the framework. ■

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