# Exploring Socioscientific Issues Through a Lens of Reciprocity

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## Abstract

High-quality elementary science instruction is crucial for laying a solid foundation for young learners while fostering an informed and responsible citizenry. Although contemporary science education has been effective at engaging students in science practice through the exploration of natural phenomena, aiding teachers in designing experiences that prepare students to tackle real-world issues as informed citizens has been more challenging. More specifically, teachers frequently feel unprepared to guide students through diverse perspectives and to incorporate indigenous knowledge into their teaching. To address this gap, the preparation of science educators must include enhancing teachers' abilities to prepare students for future challenges by integrating science with societal issues and employing multiple knowledge systems (beyond Western science) to make sense of and response to such issues. This article describes interdisciplinary 5E instruction about catch limits and overfishing that aims to develop pre-service teachers' fluency with recognizing the socioscientific nature of contemporary issues through a fishing activity and blending scientific knowledge with other Native perspectives, such as reciprocity, through their analysis of children's literature. We expect that recognizing the socioscientific nature of contemporary issues and considering them through a lens of reciprocity to promote more just understandings of and responses to SSI.

High-quality elementary science instruction is necessary to build a strong foundation for young learners, giving rise to a "well-informed citizenry and society" (NSTA, 2023). Although contemporary science instruction often succeeds in the former by foregrounding phenomena and engaging students in science practices, there is a need to better support teachers in designing experiences that will inform students' responses to the issues they encounter as citizens. Case in point: Three-dimensional (3D) learning, which interweaves disciplinary core ideas, science practices, and crosscutting concepts, lines the main pages of current Next Generation Science Standards (NRC, 2013), whereas crucial understandings about science such as "science is a unique way of knowing, *though there are other ways of knowing*," "science knowledge indicates what can happen in natural systems—*not what should happen,"* and *"*many decisions are not made using science alone, but *rely on social and cultural contexts to resolve issues*," have been relegated to the back pages (emphasis our own, NRC, 2013a, p. 6.).

The potential for expansive learning – "to learn something that is not yet there" (Engeström and Sannino, 2010, p. 2) – with regard to developing teachers' abilities to prepare future learners to overcome uncertainty and adversity is immense. If teachers are to prepare students to meet the challenges of the future, then it is vital that they engage learners in reasoning about the intersections of science and society, as well as highlight ways of knowing aside from Western science that also inform their resolution. Unfortunately, teachers often feel underprepared to do either. Regarding the former, teachers report discomfort with guiding students' consideration of the multiple opposing perspectives associated with these issues (Chen & Xiao, 2021). In the case of the latter, the exclusion of Indigenous cultures and knowledge systems in contemporary educational environments suggests that teachers could benefit from explicit exposure to pedagogies that elucidate the complexities of Indigenous cultures and knowledge with a focus on "implement[ing] culturally relevant pedagogy into their classrooms" (Abrams et al., 2013, p. 10; Greenall & Bailey, 2022).

In this article, we introducepreservice teachers (PSTs) to socioscientific issues (SSI) – complex societal challenges that require science to be resolved – through an interdisciplinary (i.e., science, mathematics, and English language arts), 5E (engage, explore, explain, elaborate, evaluate; Bybee, 2006) unit on overfishing. Our goal is to expand teachers' pedagogical expertise in two fundamental ways. For one, we hope to help teachers recognize that the issues they are preparing their students to respond to are socioscientific in nature by way of an engaging fishing activity that highlights the necessity of using science knowledge and practice *in concert with* other ways of knowing. We also sought to leverage children's literature to elucidate the importance of Indigenous ecological knowledge, namely reciprocity, for understanding and responding to SSI in a just manner.

## Developing and Facilitating Socioscientific Issues Instruction

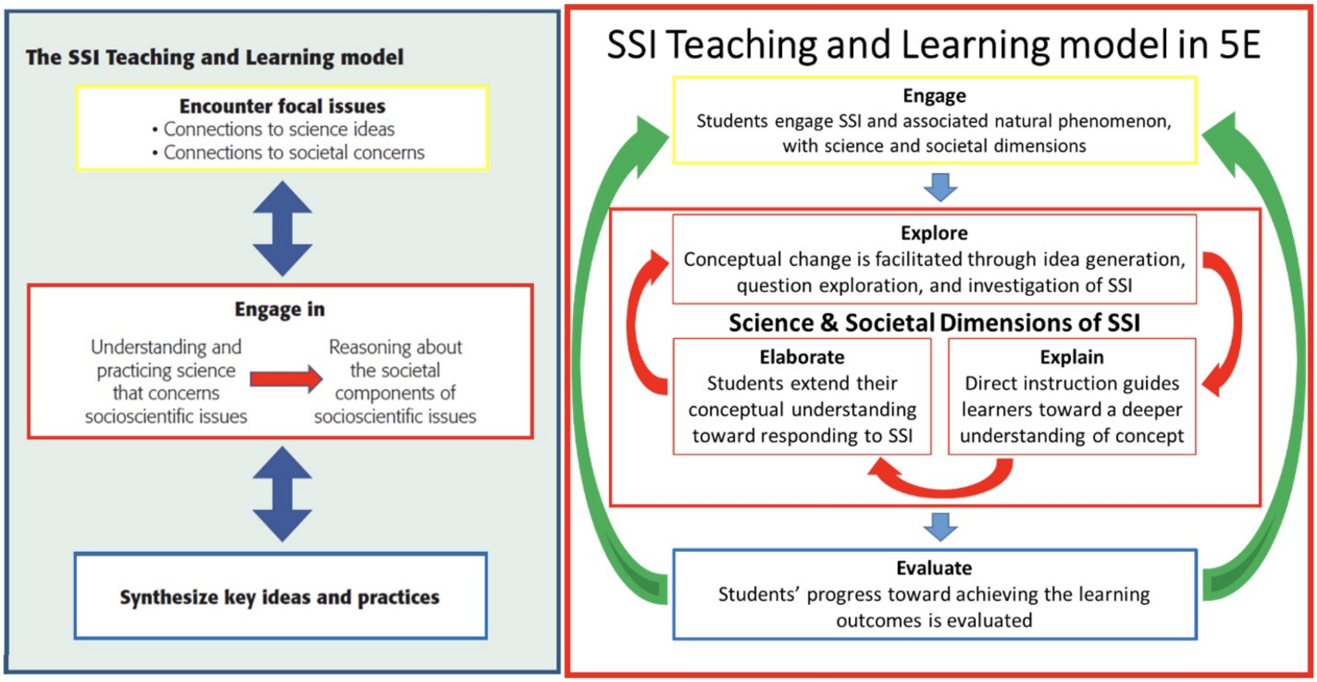
We conceive learning to be situated in the place and time in which it is taking place (Sadler, 2009). The identities of the learners that compose the communities and the goals they are pursuing, as well as the resources to which they have access (including the curriculum), all contribute to what is taken away by the learner (Bandura, 1978) – in this case, PSTs. Thus, students' ideas should be leveraged as assets for that community's learning, and the knowledge and practice that learners who compose the community will walk away with are both afforded and constrained by the composition of the community and resources to which they have access.

In this case, the PSTs are learning how to go about understanding and responding to SSI, and to frame and facilitate SSI instruction in their future classrooms. By SSI, we mean issues that are made plain by the science that undergirds them, though effectively understanding and responding to them requires addressing societal dimensions of the issue, such as morality, perspective-taking, politics, and economics. Given that multiple courses of action in response to SSI exist, none of which equally affects the stakeholders involved, it is necessary to exact moral judgment concomitantly with scientific reasoning to effectively understand and respond to SSI. For this reason, SSI instruction has been referred to as 'the gateway to functional scientific literacy' (Roberts & Bybee, 2014).

Practitioners implementing SSI instruction often refer to the Socioscientific Teaching and Learning model (Sadler et al., 2017) to frame instruction (Figure 1), where learners engage with an issue that has science and societal dimensions, and reason about the science and societal dimensions, to gain perspective on the issue, such as through engagement in science practice and perspective taking, respectfully. Ultimately, students synthesize that learning and exact moral judgment to develop a response to the issue, whether that be a letter to a congressman or a solution to be enacted that leverages the science and societal reasoning the learners engaged in.

**Figure 1**

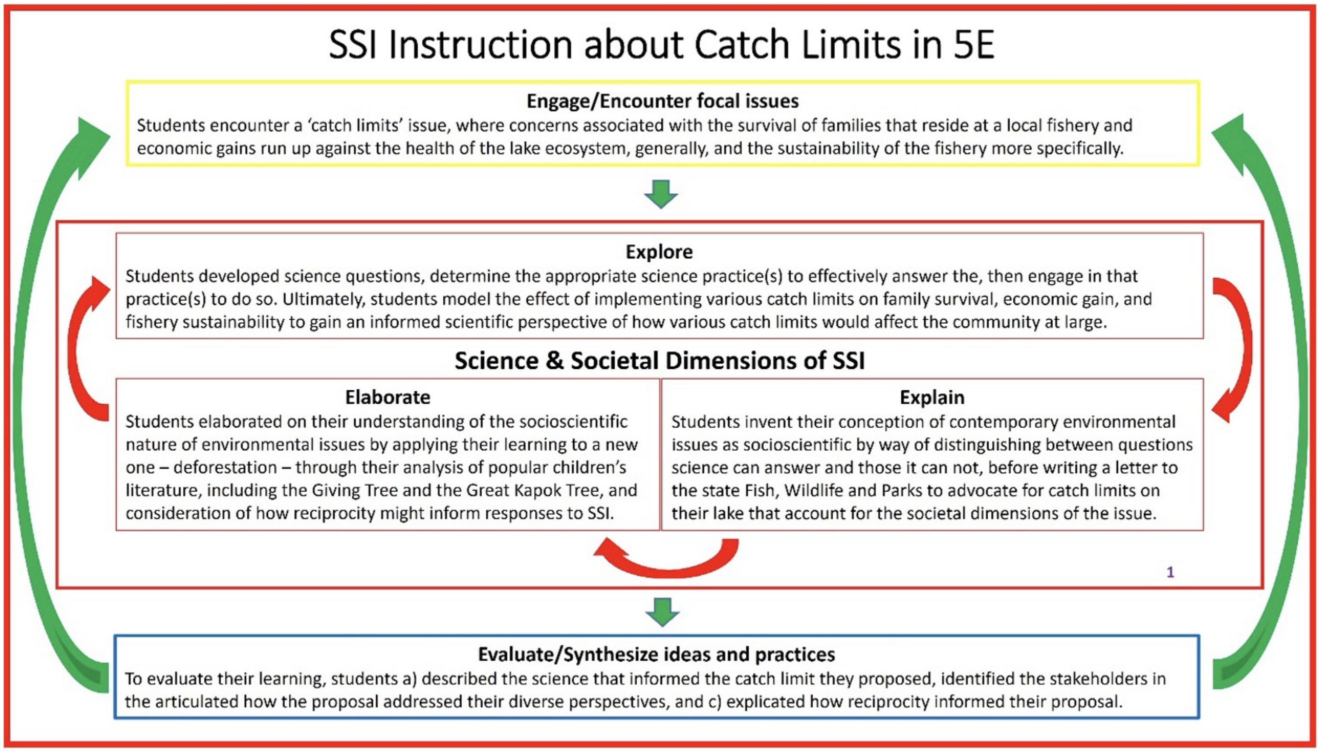
*Graphic representations of the SSI Teaching and Learning model on left (adapted from Sadler et al. (2017) and SSI Teaching and Learning model in 5E (adapted from Owens & Sadler, 2023) on the left and right, respectively.*




That said, given that practitioners may lack familiarity with the SSI T&L framework, we have framed that model in 5E to ease teachers' foray into SSI instruction (1). In doing so, teachers engage their students with a focal SSI, then have the students explore the science ideas that undergird the issue through science practice, before they explain the focal concept – also known as 'concept invention' – all of which is expected to be within a typical teacher's wheelhouse and get them off to a comfortable start to exploring SSI. This 5E strategy for teaching SSI reserves reasoning about the societal dimensions of the issue, such as taking the perspectives of various stakeholders who are differentially affected by the issues and any response to it, along with moral reasoning. This is until the 'Elaborate' phase of the learning cycle, which ensures that learners master the focal science concepts before wrestling with ideas that may not be well represented in the NGSS standards documents (though highlighted as important in the back pages). Finally, students are able to evaluate their learning by synthesizing their ideas into a product, such as an argument about what should be done in response to the issue, which accounts for both the science and societal dimensions of the issue. For an overview of the 5E instruction described herein, see Figure 2.

**Figure 2**

*Graphic representation of instruction framed with the SSI teaching and learning model in 5E and using Catch Limits as the learning context.*




## *Engage*

We took advantage of 'sense of place' in planning and facilitating this instruction about catch limits, given our location "at the junction of great trout rivers in western Montana" (Maclean, 1976, p. 1). Our students engaged with the phenomenon of overfishing – "catching too many fish at once, so the breeding population becomes too depleted to recover" (Environmental Defense Fund, n.d.) – though their consideration of a 'catch limits' issue at a fictional fishery, called Lake Hollandaise (named after a nearby lake, Holland Lake; activity adapted from Szerlip, 2003). At each table, four students composed a fishing community that lived around Lake Hollandaise – a bowl filled with 20 goldfish (Figure 3) – the maximum fish the lake was able to support (i.e., carrying capacity). At the end of each day of fishing the number of fish remaining doubled (i.e., reproduction) – up to the maximum of 20 fish. Each student was identified as a fisher and head of one of the four households that lived on Lake Hollandaise After being presented with the 'daily catch' (Figure 4) necessary for keeping their families alive and meeting desired economic incentives, each student was tasked with discretely (without talking) writing on a piece of paper:

1) What your daily catch will be (i.e., How many [whole] fish you will catch each day), and;

2) All factors that contributed to your decision as to how many fish you will take.

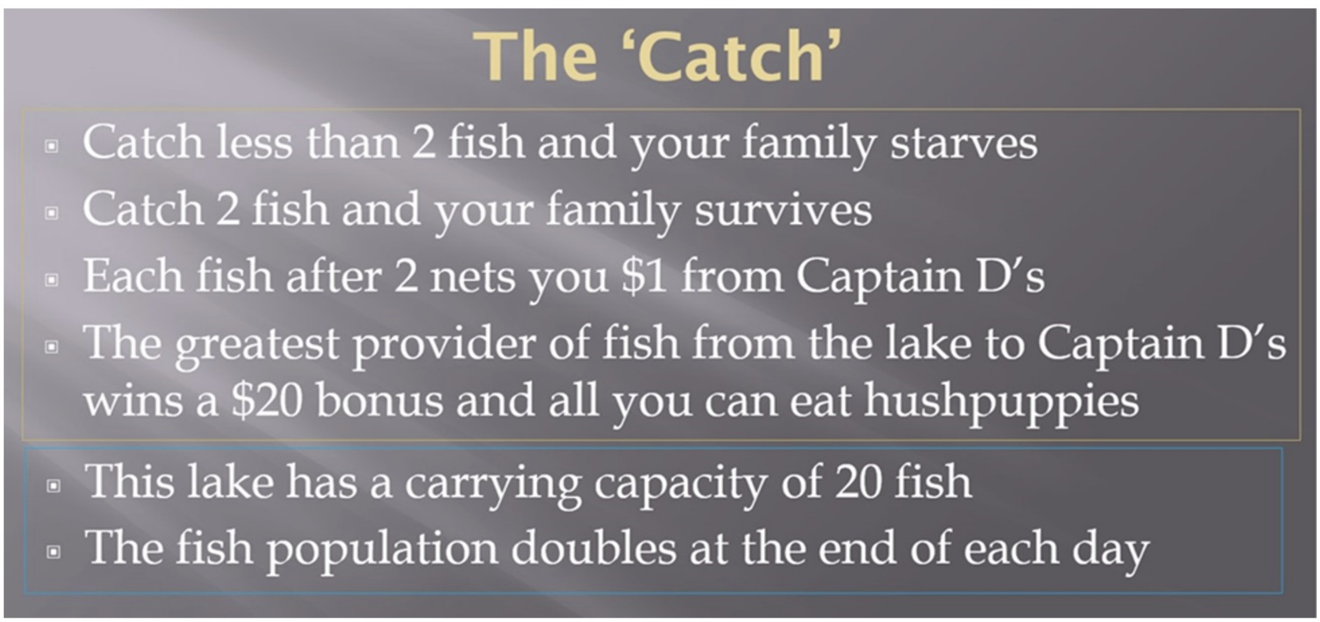
We were excited for students to use this prior knowledge and experience as assets to establish the socioscientific nature of the real-world problem later on as part of their exploration.

**Figure 3**

*Crucial components of the community fishery.*


**Figure 4**

*Criteria and constraints informing the number of fish students would commit to catching each day.*




After privately committing to a daily catch, students were asked to share with their peers the number of fish each will take and note how they felt when they heard their community members share. Some students reacted with shock and horror when a neighbor reported an outsized catch, whereas others indicated appreciation for more considerate catch commitments in their community. Regardless, an 'emotional hook' was set to help make the catch limits instruction meaningful and motivate student learning. (Allchin, 2015).

After students committed to their stated catch, we provided each of them with fishing poles (chopsticks), turned on "Fishin' in the Dark" by the Nitty Gritty Dirt Band (RHINO, 2019, 3:22) and told students to "start fishin'!" After each 'day' of fishing (when community members caught their catch commitment or all fish remaining in the lake were removed), each student recorded catch, profit, and the health of the families and the fish population at the lake (Figure 5, Table 1). This was repeated for consecutive days of fishing, continuing until either the sustainability of the total daily catch was demonstrated (i.e., the number of fish remaining each day was stable) or all families at each lake starved. Students then reflected on their community's daily catch, the health of the community (and fishery), the families that perished, and how much money each family made. By the end of the activity, students had engaged with the overfishing phenomena, experienced the concept of catch limits, and investigated their implications for the survival of their families and the health of the fishery.

**Figure 5**

*One student's Catch Log chronicling an unsustainable community fishery.*

| Day | # fish you caught: | # of fish you profited: (# fish caught-2) | # fish caught by the whole community | Did any families not catch 2 fish and therefore starve? Y/N, # | How many fish are left in the lake after fishing? | How many fish are in the lake after they reproduce? |
|---|---|---|---|---|---|---|
| 1 | 3 | 1 | 11 | No | 9 | 18 |
| 2 | 3 | 1 | 11 | NO | 7 | 14 |
| 3 | 3 | 1 | 11 | NO | 3 | 6 |
| 4 | 2 | 0 | 6 | Yes (2) | 0 | 0 |

**Table 1**

*Hypothetical catch log chronicling a sustainable community fishery – with mathematics.*

| How many fish will you catch each day? **2**<br>How many families are in your community? **4** | | | | | | |
|---|---|---|---|---|---|---|
| Day | # fish you caught: | # of fish you profited: (# fish caught-2) | # fish caught by the whole community | Did any families not catch 2 fish and therefore starve? Y/N, # | How many fish are left in the lake after fishing? | How many fish are in the lake after they reproduce ? |
| 1 | **2** | 2-2=**0** | 2x4=**8** | No | 20-8=**12** | 12x2=24 so, **20** |
| 2 | **2** | 2-2=**0** | 2x4=**8** | No | 20-8=**12** | 12x2=24 so, **20** |
| 3 | | | | | | |
| 4 | | | | | | |

Sustainable!

### *Explore & Explain*

Next, instructors provided commentary on the outcomes by indicating, “Wow, the bulk of you starved within a round or two. Sheesh! In a sentence or two, can you describe what just happened?” Students generally (and genially) pointed to community members who took more fish than the rest as the source that crashed the system. Students were reminded, “This is just one example of many that human activities can have major impacts on natural systems. How could you all have managed that situation differently for a more desirable outcome?” Responses were recorded on the whiteboard. We focused on two responses, in particular, that were provided by Heather and Renee, respectively.

- *Plan with others before determining solutions to an issue*, which we planted through our use of the silent, private information-gathering activity.
- *Consider the science that informs the issue,* which was highlighted by the responses whose factors for decision-making did not include scientific reasoning.

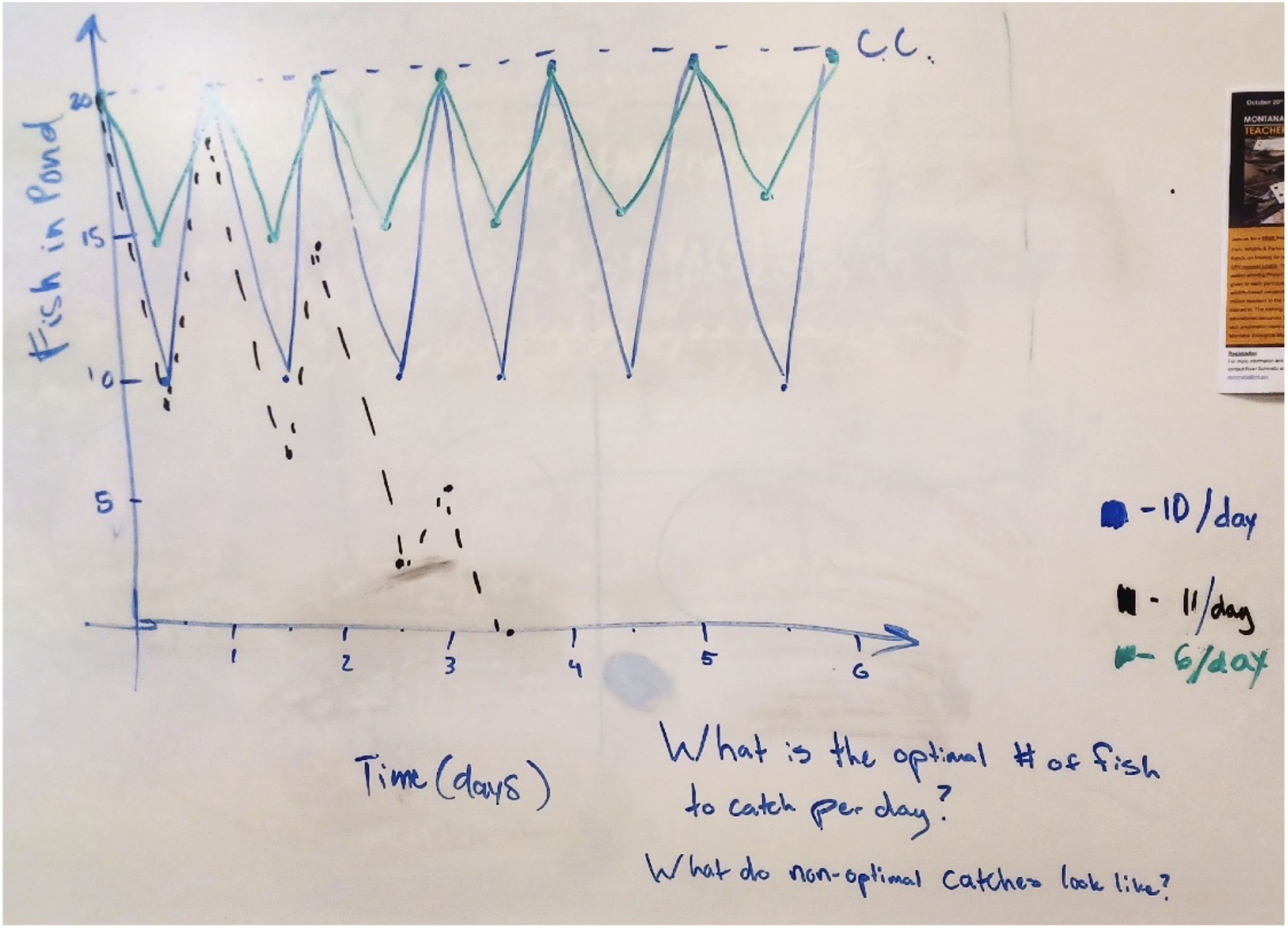
First, we explored Heather’s response that “we should have planned with others in the community before embarking on our fishing extravaganza.” Heather’s idea directly addressed disciplinary core idea ETS1.B, which we emphasized: “At…all stages of resolving problems, communicating with … the ‘stakeholders’ who are involved in and affected by the issue, is requisite to … effectively solv[ing] it”. Students recognized that without clear stakeholder communication, predicting the sustainability of the fisheries they depended on was impossible.

**Science informing the Catch Limits issue.** We also validated Renee's response – that using science to determine her catch would lead to a more desirable outcome – by referencing important aspects of the nature of science. "Science knowledge and practice are requisite to understanding issues, such as overfishing, as well as the consequences of any resolution you might settle on (i.e., the catch limits you set). Importantly, the science methods you choose to address issues like overfishing are determined by the question you are trying to answer." Students then collaborated with their community members to consider a) a question(s) that were important to ask and b) science practices they could employ to answer them in order to achieve a more desirable outcome at Lake Hollandaise. Students were then directed to the grade-level specific NGSS science practices matrix (Supplementary Material 2) and asked to spend time collaborating with the heads of household in their community to consider grade-level specific (3-5) science practice(s) that would be appropriate for answering the questions they came up with. "You will present to your classmates the question you asked, as well as the science practice you employed to answer it, with the overall purpose to better understand how we could have used science to predict sustainable catch limits prior to embarking on the fishing activity." While students were developing their questions and answering them through science practice(s), we collected the small slips of paper on which each student wrote their initial decision as to how many fish they would take each day from the lake, as well as the factors that informed their decision, which we would post on the whiteboard.

After employing their science practice of choice, we asked each community to present their science question and the product of the scientific practice in which they engaged, and to explain how their results would have them to predict the sustainability of their community's daily catch. One community asked "What is the optimal number of fish to catch per day?" They leaned on a 'developing and using models' practice for 3-5 grade: 'Develop and/or use models to describe and/or predict phenomena' – in this case, the change in the number of fish in the pond over time. Their efforts resulted in the graph seen in Figure 6.

**Figure 6**

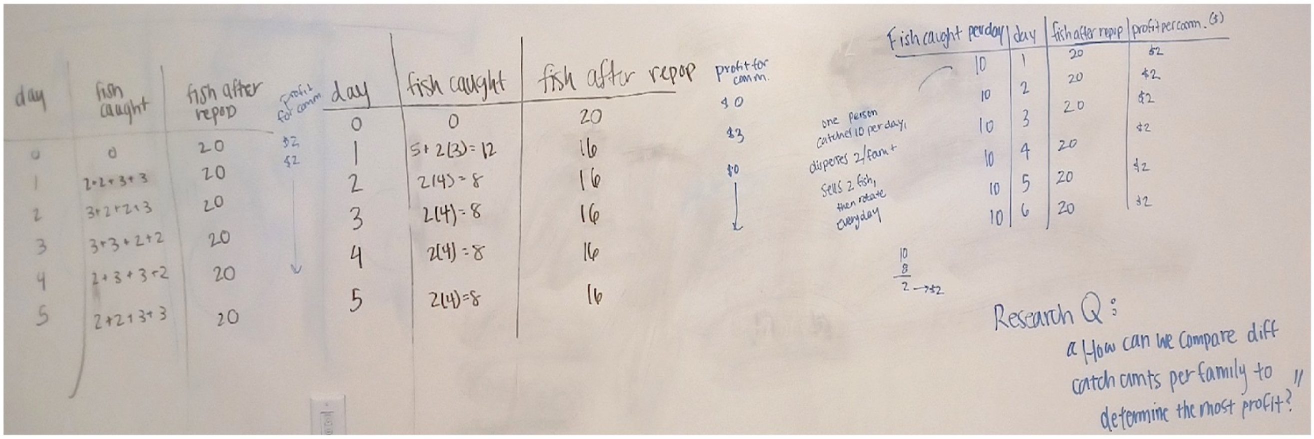
*Students scientific modeling in consideration of the optimal number of fish for the community to catch per day.*




Another community asked, “How can we compare different counts per family to determine the most profit?” Those individuals employed an ‘analyzing and interpreting data’ practice for 3-5 grade by ‘Represent[ing] data in tables and/or various graphical displays (bar graphs, pictographs and/or pie charts) to reveal patterns that indicate relationships’ – in this case, the relationship between the catch and money earned. Their efforts yielded the tables seen in Figure 7. The students recognized the graph as a more efficient representation of the catch limits’ phenomena for determining the effects of different catch limits on the population than the tables. We then reminded students that science findings are limited to questions that can be answered with empirical evidence, and asked them how they might go about testing their models. “Fill our lake up with fish and let us go fishin’ again!” responded one student.

**Figure 7**

*Students' hypothetical data, organized to compare various daily catch limits.*




We acknowledged that both groups' questions and the strategies they used for answering them were meaningful when making sense of the catch limits issue, leveraging student voice and choice while co-constructing knowledge through sensemaking. The use of modeling to predict whether the community's daily catch would be sustainable was an appropriate means for using science to inform a course of action. Because the students developed and used models to predict how catch limits would play out, we were able to highlight our students' own ideas as assets to their learning community.

There is significant overlap in the modeling practices students engage in through science and mathematics, which supports the integration of mathematics instruction into science contexts. For example, to understand and respond to this catch limits issue, representing this real-world problem "by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation" is a helpful step – a mathematical practice the first group took advantage of. In developing this instruction, we recognized this practice aligned with the fishing activity, and hoped students would employ it so that we could point to their ideas as assets. However, we were also prepared to address this mathematics standard (5.G.A.2) to ensure that students experienced meaningful integration of mathematics into science.

To further challenge students' mathematical prowess, we indicated to them that graphing wasn't the only modeling strategy that overlaps with science. In fact, incorporating important variables from the catch limits scenario could be modeled in the form of an equation. We asked students which variables they felt would be important for inclusion in such an equation and to take a crack at developing their own. After sharing out, and a bit of discussion, we decided the equation

$$\left(\frac{CC}{r}\right)\left(\frac{1}{\#fam}\right) = \frac{\#\,fish}{\#fam}$$

where carrying capacity (CC) divided by the rate of reproduction (r) and number of families (#fam) is equal to the number of fish per family that each family could harvest with no margin of error, would make it possible to predict an ideal daily catch. The equation brings into consideration the number of families composing the community, the population growth rate, and/or how carrying capacity might be different than that what was provided in the scenario described at the start of the lesson.

It is important to recognize the overlap in modeling practices students engage in through science and mathematics, which supports the integration of mathematics instruction into science contexts. For example, to understand and respond to this catch limits issue, representing this real-world problem “by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation” is a helpful step – a mathematical practice t
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**Societal dimensions of Catch Limits issue.** After addressing important science concepts and practices associated with the catch limits issue, we returned to the students’ initial responses and posted the factors they had indicated as informing each of their daily catch decisions at the start of the lesson (Figure 8). We asked the students to work within their communities to review the factors and sort them into categories that made sense to them. Ultimately, the students recognized that science was not the only factor that informed how many fish they decided to catch; societal dimensions of the issue, like economics and fairness, were also important. We highlighted the ‘socioscientific’ nature of issues like catch limits and pointed out that as elementary students advance into middle school, they need to recognize that science knowledge is important for describing and predicting the consequences of actions but is not responsible for society’s decision-making, which is also informed by other considerations like ethics and economics. We used this opportunity to distinguish between scientific and socioscientific questions, such as those they previously posed and explored through science practice:

> What is the ideal daily catch limit at this lake to maintain a stable fish population?

and the socioscientific question that could not be answered using science alone:

> How many fish should each fisher be able to catch each daily at Lake Hollandaise?

**Figure 8**

*Typical factors students cite as informing their daily catch limits, which can be distinguished for their scientific (e.g., carrying capacity) and societal (fairness) natures.*

| Typical Student Responses |
|---|
| Money/profit<br>Survival of family<br>Survival of others<br>Survival of fish<br>Sustainability<br>Fairness<br>Carrying capacity<br>Lake health<br>Peaceful coexistence |

After recognizing that addressing both science and societal dimensions is requisite to adequately resolving issues like catch limits, we introduced students to the SSI Teaching and Learning model, as well as the adaption to frame SSI instruction using the 5E learning cycle (Figure 1; Owens & Sadler, 2023). We indicated that "in this lesson, you encountered a focal issue about catch limits, which, through the factors that you indicated as informing your decisions about catch limits, had connections to science ideas *and* societal concerns", pointing back to the list of factors that students identified as scientific or societal in nature. We highlighted "fairness" as interesting, given that the degree to which any resolution is deemed to be fair is likely to be dependent on the perspectives of stakeholders with different relationships to the issue. In the end, no resolutions are likely to benefit all groups equally. When asked who the stakeholders in the catch limits scenario were, students' responses included the families fishing, fish, other organisms in the ecosystem, and tribes with fishing rights (Figure 9).

**Figure 9**

*Typical factors students cite as informing their daily catch limits, which can be distinguished for their scientific (e.g., carrying capacity) and societal (fairness) natures.*

| Class responses to “Who are the stakeholders in this issue?” |
|---|
| The Community<br>The families directly involved<br>The Lake<br>The Fish<br>Captain D’s<br>Lake management (Fish, Wildlife, and Parks)<br>Fishing pole manufacturers<br>Other organisms that compose the community<br>Indigenous individuals and their perspectives |

Up to this point in the lesson we had spent significant time understanding and practicing the science concerning the SSI of overfishing and catch limits. Students had considered societal dimensions of the catch limits issue, such as moral reasoning about what was ‘right’ as well as economic factors associated with catching more or less fish. The expectation was that students’ arguments should be more informed than those they presented at the start of the lesson. Students were asked to reconsider what the catch limit for each family should be and write a proposal to Montana Fish, Wildlife, and Parks (FWP) to advocate for catch limits for Hollandaise Lake by addressing science and societal dimensions (e.g., stakeholder perspectives). We also wanted to provide students the opportunity to support a claim at this point in the activity before engaging in multiple ways of knowing that would allow elaboration on their understanding of the relationship between humans and all living things, which could lead to more just or inclusive responses to the catch limits issue.

### *Elaborate*

After students had considered the issue through the lenses of human well-being, economics, and Western perspectives on science and society, we shifted into the elaboration phase. Our hope was to support students in extending their understanding to include the recognition that Indigenous perspectives are equally important to those of Western science when seeking to resolve SSI. More specifically, students would consider the concept of reciprocity as a moral principle to inform their understanding and responses to the catch limits issue. Likewise, we felt it important to more explicitly address the role of systems in this issue, as systems and system models is a crosscutting concept associated with both focal 3D performance expectations (5-ESS3-1 a3-5-ETS1-2). Until now, students had not explicitly considered Indigenous perspectives or the components and interactions which make up the systems related to the issue.

To address these concerns, we selected three children's books to provide exemplary situations in which characters make decisions in a novel context of resource exploitation – timber harvesting. First, students read *Robin and the Marvelous Maple* (Winestein, 2022), inspired by Robin Wall Kimmerer's (2013) book *Braiding Sweetgrass*. In this book, Robin learns about reciprocity from her teacher and embarks on a mission to exhibit reciprocity with the natural world. After reading, students were asked to define 'reciprocity' as they understood it from the book and describe the relationship between Robin and the Maple trees. As a class, we settled on a definition of reciprocity as give-and-take between Robin and the Maple for the mutual benefit of both. The relationship between the Robin and the Maple was one of give-and-take, with Robin receiving sugary syrup and, in return, caring for the health of Maples everywhere.

To aid students' elaboration on their understanding and responses to the catch limits issue with a focus on reciprocity, as well as their characterization of the relationships of humans and other beings, we asked them to consider whether and how reciprocity played out in the following books and to characterize the nature of the relationship between the main character and the focal resource:

- *The Giving Tree*: a story that traces the relationship of a boy and a tree as the boy grows from toddler to old man (Silverstein, 1964).
- *The Great Kapok Tree:* a story about a man who enters the forest to harvest a tree, but changed his mind when animals who inhabit the tree urge him not to (Cherry, 1990).

Students compared and contrasted the human-tree relationships in each story and answered the question, "How was reciprocity established in each, if at all?" Students generally indicated that whereas there may have been some reciprocity between the boy and the tree at the start of *The Giving Tree*, the relationship became one-sided as the boy aged and began treating the tree as a resource for his own benefit. Students were also challenged to characterize the human-tree relationship in *The Great Kapok Tree as reciprocal*, as the lumberjack left empty-handed, though students did point out that the awareness he gained from the experience certainly had value. Students were then asked to choose one story or the other (*The Giving Tree* or The Great Kapok Tree) and write an alternate ending such that reciprocity was clearly exhibited between the human and other-than-human characters.

With a firmer understanding of reciprocity, we then turned our attention to systems. The catch limits issue, as well as The Giving Tree, are framed in terms of humans and a species with a human-first mentality, whereas The Great Kapok Tree explored more complex natural systems. We highlighted to students that in The Great Kapok Tree the canopy ecosystems that were described are complex, and tasked them with developing a model that reflected this. We then showed them the model in Figure 10, with both abstract (left) and concrete (right) observations, and asked them to compare this model with those they created.  Students were then asked to return to the catch limits exercise to create a model that accounted for the complexity of the lake ecosystem by considering other-than-human stakeholders who would be also affected by the catch limits issue such as the fish who feed on trout (e.g., sculpins, smallmouth bass) as well as larger predators (e.g., herons, eagles, raccoons) (Figure 11).

Finally, students were challenged to consider reciprocity from a systems perspective. As a scaffold, we simplified this task by having them consider a single predator, such as a bald eagle who also depend on the fish. Students then speculated what reciprocity might look like in the context of the catch limits issue, such that a give-and-take was exhibited by all living things implicated in the issue. Finally, we asked students to consider how acting with reciprocity could change the impacts that overfishing had on the aquatic and surrounding ecosystems at Lake Hollandaise.

**Figure 10**

*Conceptual representation of a complex system (adapted from Filotas et al., 2014).*

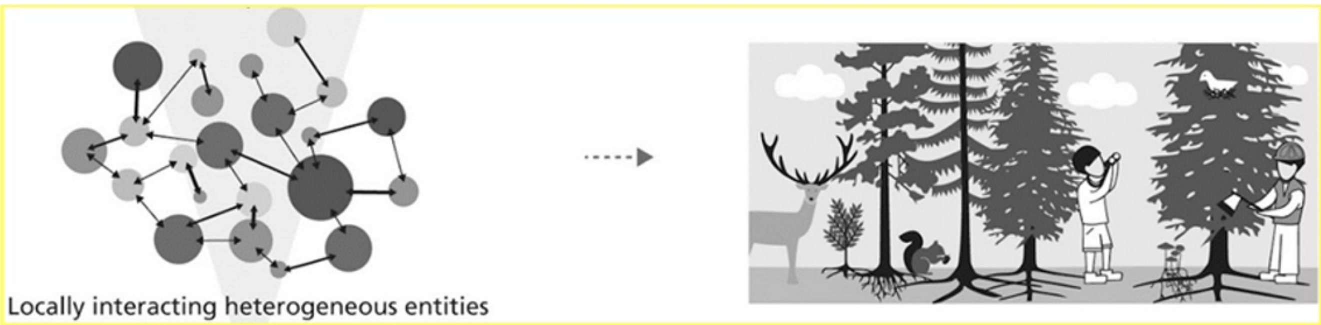
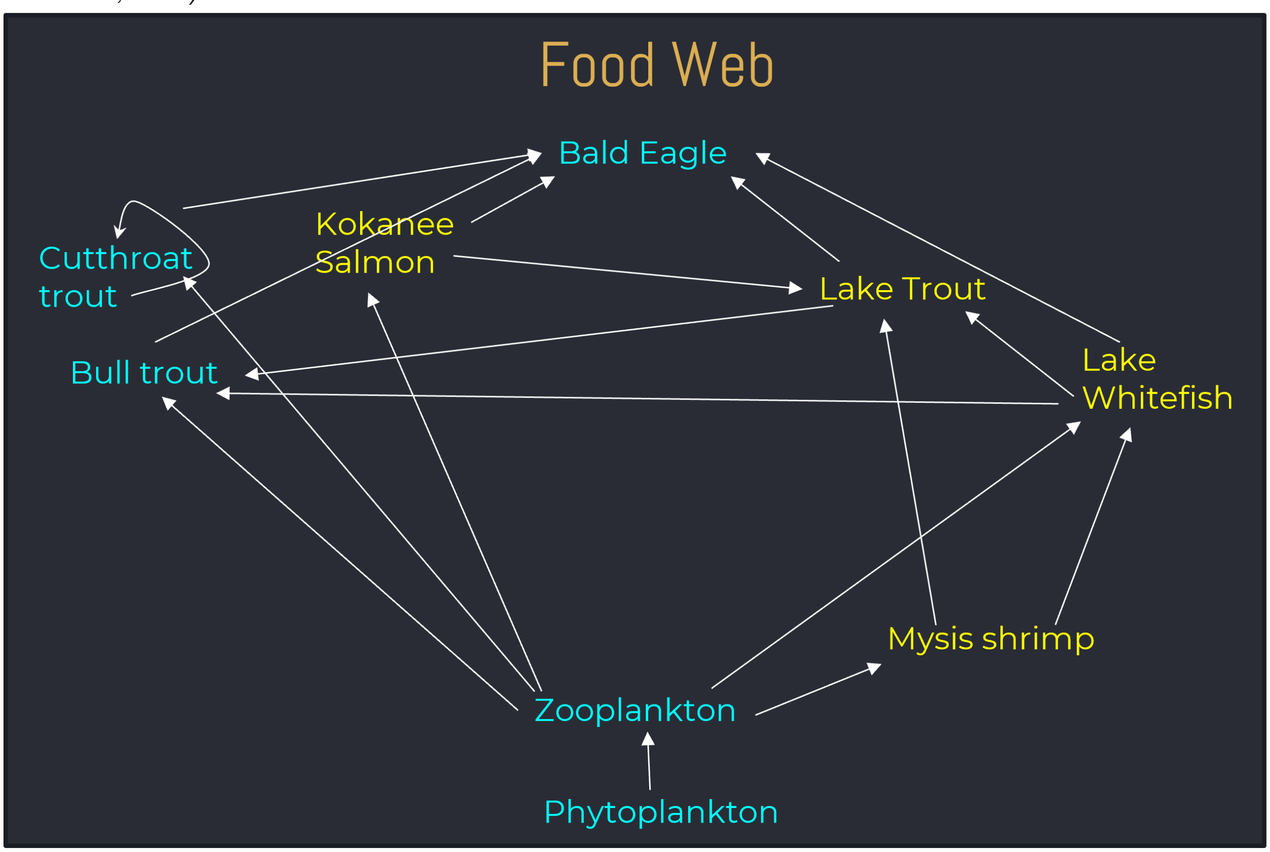



**Figure 11**

*Other-than-human stakeholders of the lake ecosystem who would be affected by the catch limits issue (adapted from Rost, 2022).*




### *Evaluate*

Students were asked to refer back to the two previous catch limits they proposed (during the ‘Engage’ portion of the instruction, just before the fishing activity, and in their FWP letter as part of ‘Explain’), and determine and describe the extent to which those explanations exhibited reciprocity. Then, students were tasked with reconsidering the arguments they used to support the daily catch commitment they initially proposed and responding to the following prompts:

1. Explicate the science that informs the catch limit you proposed (provide model).

Students’ references to science in their proposals often related to factors, such as that related to survival of the families and the fish: the carrying capacity of the lake, the starting population of fish, the number of families in the community, the requisite number of fish caught for family survival, and the reproductive rate of the fish. Most students used mathematical calculations representative of those practiced in the classroom to support their arguments. For example, one student offered the following model that enabled them to predict a catch limit that would maximize the outcome for the fishers of the community.

Catch Limit = (Carrying capacity/2) / Number of families

Students also organized their evidence graphically using the evidence from trials to demonstrate and support the catch limit they proposed (Figure 12). However, although students were generally able to reference the tables and graphs they had used in calculations, some struggled to leverage them as evidence in the letters they wrote to the FWP. For example, modeling in our fishing scenario would indicate that, for a community of four fishers, a community catch limit of 8 fish would sustain the community, *although a couple more fish could still be taken* (for money or by, say, an eagle) while sustaining the fish population – this is where the rub of any argument about catch limits in this context lies. Should those extra fish be an economic boon, or should they be left for other-than-human organisms that compose the lake ecosystem? Given that the catch limits these students proposed often maximized the catch limits available for the number of families residing at the lake, it did not appear they were accounting for the needs of other predators who prey on these fish, such as those identified by PSTs after reading The Great Kapok Tree. Future implementations should encourage students to reflect upon and integrate their work surrounding complex systems into the letters they wrote.

2. Identify the stakeholders in the issue and how your proposal considers/addresses their diverse perspectives (provide model).

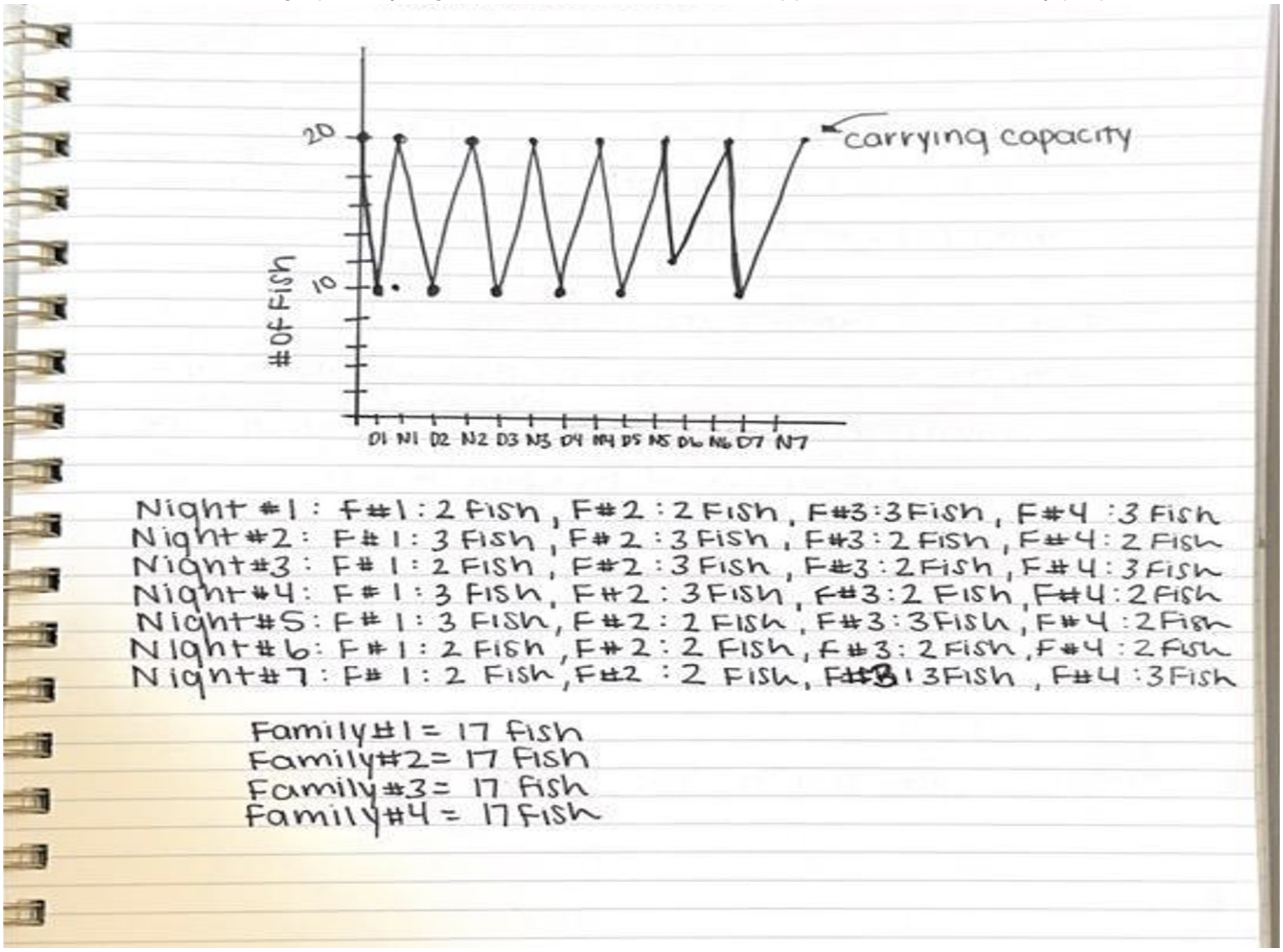
We found the vast majority of students to identify as stakeholders in the catch limits issue to be the families and the fish. A few students identified other stakeholders, such as Native Americans, recreational anglers, and the local economy. All but one student empathized most strongly with the families fishing the lake and presented this perspective as a priority over all other stakeholders. The students who did recognize other stakeholders, including fish, predators and the economy, still framed these stakeholders in relation to their impact on humans. In any case, the importance of considering other stakeholders came across as human-centered. The survivability of fish and ecosystem health were deemed important to enable the continued harvesting of fish by humans, and supporting tribal fishing rights was secondary to the survival of the fishing families. Students who did make reference to Indigenous communities referenced Montana tribes having tribal rights and needing to seek input from these communities. Although students were able to identify some stakeholders and write from the perspective of one stakeholder, they would benefit from mentorship in diverse perspective-taking and multiple ways of knowing.

3. Articulate how reciprocity informed your proposal.

Most of the students' proposals mentioned reciprocity and indicated that reciprocity informed the way they designed their proposals. Their considerations of reciprocity varied, but generally framed reciprocity as sustained survival of the focal stakeholders (human and fish), mutual respect for both stakeholders, and mutual benefit for both stakeholders. Most commonly, students framed the families and the fish in the reciprocal relationship, and recognized that the survival of fish and humans were interdependent. The most pervasive narrative among students showing reciprocity between fish and humans was one in which humans got food from fish and in return, the fish population was maintained (from both extinction and over population). This raises the question: Is the purpose behind this reciprocal relationship to allow for continued commodification of the fish in the lake?  The students who proposed a catch limit with reciprocity in mind found it to be a useful tool in writing a solution that promotes sustainability, cooperation, and adaptability. A lens of reciprocity seemed to heighten students' ability to create a solution that accounted for the needs of stakeholders beyond just the humans. These students recognized that the system was complex, multiple stakeholders were affected, and the solution needed to be sensitive to all parties involved.

**Figure 12**

*One student's evidence, graphically organized to demonstrate and support the catch limit they proposed.*




## Conclusion

After having completed the instruction, students widely recognized that fishing activities had effects on the fish and humans, and that any solution should reflect the survival needs of both parties. There was variation in how reciprocity can serve both stakeholders, specifically how human involvement demonstrated reciprocity for fish, though the majority of students were able to use a lens of reciprocity to strengthen their catch limit proposal. Instructors should recognize that there are many ways for humans to show reciprocity for their natural landscapes and strengthen students' ability to recognize and integrate these. For example, one student mentioned humans showing reciprocity for the fish by being a steward to the landscape, thus improving the health of the fish and ecosystem. Undoubtedly, these children's books and this model system served to create a meaningful learning environment for students to explore catch limits and come to their own understandings of reciprocity in the context of responding to a socioscientific issue like overfishing.

With this article, our intention was to model exemplary SSI instruction so as to expand teachers' pedagogical expertise in two ways. First, we sought to ensure that the socioscientific nature of these issues was made explicit and at the forefront of teachers' and students minds, which we accomplished this through a fishing activity that leveraged students' ideas as assets for their recognition that addressing both science and societal dimensions is requisite to effectively understanding and responding to SSI. Secondly, we sought to make plain that SSI are best understood and resolved when Western science is used in concert with other ways of knowing, such as Indigenous ecological knowledge, which we accomplished through students' analysis and creative revision of children's literature about their relationship with other-than-human organisms that compose the communities they inhabit. It is our hope that this work aids teachers in confidently addressing societal dimensions of SSI (e.g., perspective taking, moral reasoning) while imploring their students to complement their use of Western science with Indigenous ways of knowing that situate humans more precisely within the ecosystems they often see themselves apart from and lead to more equitable outcomes when responding to SSI.

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## References

Abrams, E., Taylor, P. C., & Guo, C. J. (2013). Contextualizing culturally relevant science and mathematics teaching for indigenous learning. *International Journal of Science and Mathematics Education, 11*, 1-21. https://doi.org/10.1007/s10763-012-9388-2

Allchin, D. (2015). Hooks, Lines, & Sinkers. *The American Biology Teacher. 77*(9), 718-720. https://doi.org/10.1525/abt.2015.77.9.14

Bandura, A. (1978). The self system in reciprocal determinism. *American Psychologist, 33*(4), 344–358. https://doi.org/10.1037/0003-066X.33.4.344

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins, effectiveness, and applications. *Biological Sciences Curriculum Study*. [accessed November 8, 2023]. https://bscs.org/reports/the-bscs-5e-instructional-model-originsand-effectiveness/

Chen, L., & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review, 32*, 100377. https://doi.org/10.1016/j.edurev.2020.100377

Cherry, L. (1990). *The great kapok tree*. Harcourt Brace Jovanovich.

Engeström, Y., & Sannino, A. (2010). Studies of expansive learning: Foundations, findings, and future challenges. Educational Research Review, 5(1), 1-24. https://doi.org/10.1016/j.edurev.2009.12.002

Environmental Defense Fund. (n.d.). *Overfishing: The most serious threat to our oceans*. https://www.edf.org/oceans/overfishing-most-serious-threat-our-oceans#:~:text=What%20is%20overfishing%3F,animals%2C%20which%20are%20then%20discarded.

Greenall, R. F., & Bailey, E. G. (2022). An Instructor's Guide to Including Traditional Ecological Knowledge in the Undergraduate Biology Classroom. *CBE—Life Sciences Education, 21*(4), es6. https://doi.org/10.1187/cbe.21-12-0340

Kimmerer, R. (2013). *Braiding sweetgrass: Indigenous wisdom, scientific knowledge and the teachings of plants*. Milkweed editions.

Maclean, N. (1976). *A river runs through it, and other stories*. University of Chicago Press.

National Research Council. (2013). *Next generation science standards for states by states: Appendix H. Understanding the scientific enterprise: The nature of science in the next generation science standards.* Retrieved from: http://www.nextgenscience.org/sites/ngss/files/Appendix%20H%20-%20The%20Nature%20of%20Science%20in%20the%20Next%20Generation%20Science%20Standards%204.15.13.pdf.

National Science Teaching Association. (2023). Position Statement: Elementary School Education. National Science Teaching Association, 1-4. https://www.nsta.org/nstas-official-positions/elementary-school-science

Owens, D. C., & Sadler, T. D. (2023). Socio-scientific issues instruction for scientific literacy: 5E Framing to enhance teaching practice. *School Science and Mathematics, 124*, 1–8. https://doi.org/10.1111/ssm.12626

Roberts, D., & Bybee, R.W. (2014). Scientific literacy, science literacy, and science education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education, Volume II* (pp. 545-558). Routledge. https://doi.org/10.4324/9780203097267

Rost, L. (2022). The eagle has fallen: Flatline of the Flathead Lake ecosystem. *The Science Teacher, 89*(6), 45-51. https://www.nsta.org/science-teacher/science-teacher-julyaugust-2022/eagle-has-fallen

Sadler, T. D. (2009). Situated learning in science education: socio‐scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1-42. https://doi.org/10.1080/03057260802681839

Sadler, T.D., Foulk, J.A, & Friedrichsen, P.J. (2017). Evolution of a model for socio-scientific issue teaching and learning. *International Journal of Education in Mathematics, Science and Technology, 5*, 75-87. http://DOI:10.18404/ijemst.55999

Silverstein, S. (1964). *The giving tree.* Harper & Row.

Szerlip, J. (2003). The Tragedy of the Commons. Accessed February 15, 2024 https://www.scienceteacherprogram.org/biology/szerlip03.html

RHINO. (2019, April 26). Nitty Gritty Dirt Band – Fishin' In The Dark (Official Audio). YouTube. https://www.youtube.com/watch?v=jBRfkxUAyOk

Weinstein, M.H. (2022). *Robin and the marvelous maple.* Weinstein.