# Supporting Elementary Learners to Explore Causal Interaction Patterns

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**Abstract:** This study explored how scientific modeling supports 3rd-grade students' consideration of causal interaction patterns in the context of a socio-scientific issue. Four 3rd-grade teachers enacted a new unit on ecosystem interactions using an approach we call model-oriented issue-based learning. We varied the order of the modeling and issue lesson sequence across participating classrooms to explore how modeling supported students causal reasoning on the issue. In two classrooms, students had a modeling lesson between taking an initial and final position on an issue while in two classrooms, they did not. The socio-scientific issue writings from the students that had the modeling lesson in-between showed growth in their consideration of causal interactions, while students from the other two classrooms did not.

## Major issues and significance

Learning about ecosystems involves learning about causal interaction patterns. Causal interaction patterns include multiple causes and effects that span both spatial and temporal dimensions. The cause and effect occurrences may not be linear but rather demonstrate multi-directionality in which causes become effects and effects become causes (Perkins & Grotzer, 2005). Understanding causal interaction patterns is an important aspect of systems thinking and is foundational to developing an understanding about ecosystems. Research on how to support learning about causal interaction patterns has focused on students in the upper grade levels (e.g., Eilam, 2012). These studies note the challenges older students have in understanding cause and effect occurrences. Ben-Zvi Assaraf & Orion (2010) recommend that considering causal interactions should begin in the elementary classroom.

While content about ecosystems is frequently included in elementary science instruction, ecosystem causal interaction patterns are typically not part of these learning opportunities (Hayes, Plumley, Smith, & Esch, 2017). This may be because of the challenges elementary students have in defining causal interaction patterns. Elementary students hold naïve biological causal connections in which they infer relationships from evidence obtained through observations and experiences (Grotzer & Bell Basca, 2003). This reasoning is personal as it is situated in their psychological understandings about themselves, their belief structures, and their emotional perspectives on their experiences. Personal reasoning leads to teleological explanations where the result *is* the explanation (the plant bends to reach sunlight), and/or anthropomorphic, where the causality is drawn from the students' perspective of themselves so the reasoning is agent-based (when the plant is thirsty, it drinks).

We hypothesized that combining scientific modeling and socio-scientific issues (SSI) could serve as an important bridge for students to consider ecosystem causal interaction patterns. Modeling is an epistemic practice in which learners develop, evaluate, and revise representations of an entity, phenomenon, process, or system. These representations can describe, explain, and predict. Modeling is essential to understanding system behavior because as students develop their models, they have a way to represent both hidden and visible components while showing the interactions that bring about system behavior (Lehrer & Schauble, 2012). SSIs represent complex societal issues with substantive connections to science that are at the intersection of social and natural systems, such as climate change and food scarcity (Zeidler, 2014). The process of negotiating an SSI and developing a position or solution for that issue requires thinking about the system where the issue resides (Sadler, 2009). Research related to the use of SSI in classrooms has yielded evidence of the positive impacts of framing science instruction with issues on student learning of science concepts and understandings of the epistemic underpinnings of science (Evagorou, Jimenez-Aleixandre, & Osborne, 2012). Yet, with very few exceptions, (e.g., Evagorou et. al, 2012) there is little empirical information to guide how SSI supports elementary students' learning or how they negotiate connections between science concepts and real-world issues.

To undertake this work, we used *model-oriented issue-based* (MOIB) *learning* in which modeling practices are embedded within an SSI learning experience. We use MOIB learning as a framework to inform both the design and analysis of this intervention to explore if instruction about modeling and asking students to create their own ecosystem interaction models increased the complexity of the causal interaction patterns they used to justify their positions on an ecosystem-related SSI. We ask the following research questions: (1) *Does a modeling experience improve students' consideration of causal interaction patterns when taking a position on an SSI? (2) In* *what ways does a modeling experience affect students' consideration of causal interaction patterns when taking a position on an SSI?*

## Methodological approach

This sequential mixed-methods (Creswell & Plano Clark, 2011) study took place in four U.S. 3rd-grade classrooms (student age 8 – 9 years old) at the same school in a small Midwestern city where 50.1% of the school population was eligible for free/reduced lunch. The classroom teachers had worked together to plan, review student work, and coordinate activities for the previous 13 years.

The unit featured the reduction of Monarch butterfly migration as a focal issue and opportunities for learners to explore ecological interrelationships within an ecosystem (for materials, see http://ri2.missouri.edu/ri2modules/MONARCH/intro). The school had two soccer fields, so the unit began with the following prompt: 'Should our school turn one of our soccer fields into a garden to attract butterflies?' This was writing one (W1). Next, students in Classrooms 1&2 began the modeling lesson, which took four days, occurring for 30 – 45-minute periods each day, and then completed an SSI lesson. Students in Classrooms 3&4 completed the SSI lesson then completed the modeling lesson.

The teachers enacted the modeling lesson using the metamodeling prompts in the lesson which included *purpose of models and modeling*, the *nature of models and modeling*, the *process of modeling*, and *evaluating* (Schwarz & White, 2005). At the end of the modeling lesson, students created their first model in response to the question "How do all kinds of animals, insects, people, and plants interact with their environment?" Students then answered three reflective prompts about their models: (a) What does your model show? (b) Why do you think this is how animals, insects, people, and plants interact with their environment? (c) What observations have you made to help you understand how animals, insects, people, and plants interact with their environment? These student products are referred to as model one (M1).

The SSI lesson introduced students to the issue of Monarch butterfly declines. Students watched a short segment of a movie showing Monarch migration from Mexico to Canada. They used state department of conservation data to construct a pictograph of the number of Monarchs migrating through the state for the past 20 years. Teachers read a book to the students about the relationship between Monarch's and Milkweed and the students worked in pairs on their iPads (2:1 iPad) to explore why Monarch migration numbers were decreasing and report their findings during an all-class discussion. After this they wrote to the question *Should our school turn one soccer field into a garden to attract butterflies?* Throughout the remainder of the manuscript, we refer to this SSI writing as writing two (W2). The curriculum did not advocate for a particular stance on the issue, and the teachers were explicit with the students that they were to use their model and own ideas on the issue.

*Data collection.* The difference in the lesson sequence between Classrooms 1&2 and 3&4 provided us with an opportunity to explore causal reasoning differences between those students that had a modeling lesson between W1 and W2 (Classrooms 1&2) and those that did not (Classrooms 3&4). We collected and analyzed data from students that were present for W1, W2, and M1 so our data corpus was made up of 54 students across the four classrooms (Classroom 1 and 2, n = 30; Classroom 3 and 4, n = 24). We also interviewed two students from each classroom (n = 8) after W1, W2, and M1 (interview length ranged from 9-26 minutes), and we observed, took field notes, and audio-recorded all enactments of the modeling and SSI lessons.

*Data Analysis.* We scored the writings using a rubric based on theory about causal interaction patterns developed from Perkins & Grotzer (2005). Two team members used the rubric to score the same 10% of the sample for interrater reliability: Cohen's *Kappa* was 0.879, $p = 0.000$, indicating strong agreement. The data corpus was divided among two scorers to complete that analysis. The rubric is provided in Table 1.

Table 1. Causal Interaction Pattern Rubric

| Level | Type of Reasoning | Student Writing Example |
|---|---|---|
| 1 | Personal: Anthropomorphic, egocentric and/or aesthetic situated in everyday experiences and concrete observations | I think we shouldn't because I use every soccer field. (S34, W2) |
| 2 | Relational: Relationships between organisms without specifying how changing one element would affect the other element. | We have three soccer fields and because they [butterflies] can lay their eggs on the leaves or grass. (S6, W1) |
| 3 | Causal: Single cause and effect, causal chain, and/or bi-directional where two elements have simultaneous cause and effects on each other | The butterflies need pollen and give the pollen to other flowers. (S10, W1) |

## Major findings

### Statistical analysis of W1 and W2

Students' writing scores were ordinal data so we used the non-parametric Kruskal-Wallis to look for differences in W1 across the four classrooms to rule out if students in one classroom began the study significantly higher in their reasoning type than other students. There was no statistical difference across the four classrooms for W1 $H$: 2.884, $df = 3$, $p = 0.410$, where the majority of students were at level 1 which was personal and concrete. Next, we used the Wilcoxon Signed Ranks Test, to look for differences from W1 to W2 between Classrooms 1&2 (*did* do the modeling lesson between W1 and W2) and Classroom 3&4 (*did not* do the modeling lesson between W1 and W2). We did find a statistical pre/post difference in Classrooms 1&2 ($Z$ test: -2.961, p = 0.003), but not in Classrooms 3&4 ($Z$ test: -1.732, p = 0.083). For Classrooms 1&2, 46% (14 students) remained at level 1, while we saw increases in the quantity of level 2 responses to 30% (9 students) and level 3 responses to 23% (7 students). However, for W2 in Classroom 3&4, the majority of the responses (79%) remained at level 1 while only two students scored a level 2, and one student scored a level 3.

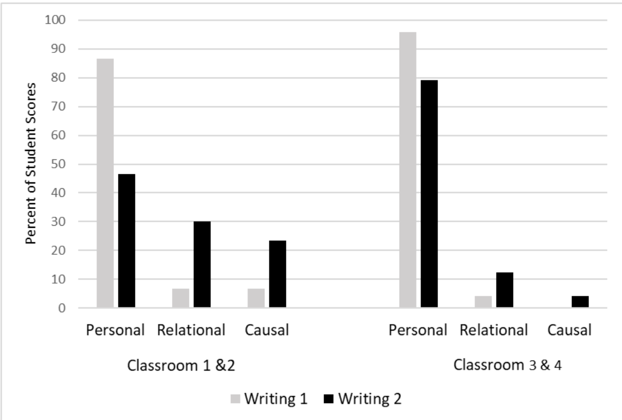


Figure 1. Growth from Writing 1 (W1) to Writing 2 (W2) across classrooms 1&2 and 3&4.

### Student artifacts

We used individual students' W1, M1, and W2 and interviews to build descriptive cases to elucidate reasoning patterns and found three trends from W1 to W2: 1) shift from personal to causal reasoning, 2) shift from personal to relational reasoning, and 3) remain at personal reasoning throughout. We used the reasoning descriptions in Table 1 to characterize the causal reasoning dimensions for the writings. Due to space limitations we focus on the large shift from personal to causal reasoning and the shift from personal to relational that occurred in Classrooms 1 and 2.

*Personal to causal reasoning*: Five students were within this group. Within the models these students demonstrated signs of causal reasoning about ecological relationships. For example, in W1, Ola was against the proposal to turn the soccer field into a garden and provided the personal reasoning of "people would get angry." It was not clear who would be angry, we suspected that she was concerned that people who liked playing soccer would not have enough space to play. Ola's reasoning is personal in W1 because her position was solely based on her concern about anger among her peers. In M1, Ola included multiple predator-prey relationships such as a mother deer running from a wolf and wrote about her model that it was a food chain ecological relationship: "a gorilla eating a fish that eats another fish." In W2, Ola used similar causal reasoning writing that butterflies would die without the garden and considered how their death would affect other species in the food chain including humans: "Yes [we should turn the soccer field into a garden], because without it butterflies would start dying and we wouldn't have fruits and most of food chain would die and there would be less humans." (Ola, W2). The linear cause and effect chain that Ola used in W2, was also in her M1, even though the organisms she mentions in W2 and M1 were not the same. Specifically, she made the causal link between the garden and the butterfly, fruits, and other species including humans. Given the similar reasoning pattern we observed in her model and W2, we hypothesize that, by engaging in the modeling activity, Ola was able to recognize the chains of cause and effect embedded in an ecosystem and applied it to the issue context presented in W2.

*Personal to relational reasoning:* Seven students were in this group. In these cases, students were able to identify key relationships in their models and applied similar relationships in their second writings (W2). This group also used mixed reasoning in W2 incorporating both personal and relational reasoning. For example, in

W1, Hannah used personal reasoning in her position against turning the soccer field into a garden because "the soccer fields help kids get energy out." She focused her reasoning on students' recreational needs. In M1, Hannah included multiple relationships between predators and prey such as a big fish eating a little fish and little fish eating a plankton. In W2, Hannah changed her opinion on the issue and advocated for turning the soccer field into a garden. She wrote, "Yes, because butterflies also help pollinate the flowers, and a very pretty to see when the fly by butterflies are dying out because they don't have enough food." In W2, Hannah implies that butterflies eat nectar from the flowers, but since she did not articulate a specific relationship only that butterflies "help pollinate flowers," we did not code her response as causal. Yet, Hannah was able to identify these relationships between system components in both her model and W2, which indicated an influence of the modeling activity on W2. There is also mixed reasoning within Hannah's W2. In addition to relational reasoning she included personal reasoning that butterflies are "very pretty to see" in W2. Using two kinds of reasoning within one response was typical among students in this group. It suggests that, while these students were able to identify relationships in a system, their personal feelings were also still important for their negotiation of the issue.

## Conclusions and implications

Prior work in the elementary classroom has not included asking students to develop and use models of their own design to consider causal interaction patterns that underly system behavior (e.g., Grotzer & Bell Basca, 2003). Our results suggest that the modeling experience between W1 and W2 helped to improve more students' reasoning complexity between W1 and W2 than when students did not have the opportunity to model. Students were able to shift from personal to relational and, in some instances, to causal reasoning when taking a position on an issue. As shown in each example, students were able to use their models to highlight specific ways that interactions occur within ecosystems, using a food chain. Building this understanding appeared to help students shift from a focus on personal (people like to play) to consider how interactions occur in an ecosystem. This degree of shifting did not occur in Classrooms 3&4 where the teachers enacted the modeling lesson after the SSI lesson. The models within these classrooms were frequently drawings of butterflies without interactions.

Prior work on ecosystems learning shows how phenomena-based approaches can be productive for learning about causal interactions (Grotzer & Bell Basca, 2003). We contend that organizing instruction around phenomena alone does not go far enough toward achieving the goal of developing students that are able to apply their understanding beyond the classroom to global issues they will encounter within their lives. Students need opportunities to practice scientific modeling in the negotiation of issues that matter beyond their classrooms.

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