Reasoning About Causal Complexity in Science and Beyond

The Understandings of Consequence Project
Project Zero, Harvard Graduate School of Education

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Introduction

Overview

Understanding science concepts deeply often involves thinking about cause and effect differently than we are used to. Even the words “cause and effect’ can be misleading because they imply one cause and one effect The purpose of this module is to introduce broader notions of causality to students. It invites students to push beyond simple linear notions of “this makes that happen” towards other forms—non-linear, non-sequential, bi-directional and so forth.

Each of the Understandings of Consequence Science Units teaches the causal concepts that are needed to understand the science concepts in that particular unit—the causal patterns taught are those situated within the concepts and are taught in service of the concepts. This module was designed at the request of teachers who wanted to introduce causal patterns separately, before teaching the science units. Other teachers wanted background units to help reinforce the causal concepts so that students would be more likely to transfer them to new topics. This module is a response to those requests.

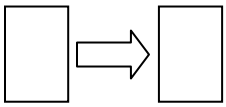
Many of the teachers with whom we have had the pleasure of working over the past ten years have noted that the causal patterns taught in the science units were important beyond science. They applied them to learning in social studies, health, language arts, and so on. This stand-alone introduction to the causal patterns can offer a jumping off point for lessons beyond science. These lessons are intended for use in middle school but can be adapted for use with younger and older students.

The patterns taught in the module are ones that the students and teachers have found to be helpful and to capture many of the dynamics that they are reasoning about across the curriculum. They are not the only possible causal patterns, but offer a useful starting place. [1]

[1] A more in-depth discussion of the nature of causal complexity and how we reason about it is forthcoming in a book by Tina Grotzer, the developer of this module.

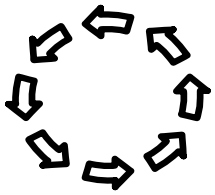
Understanding Different Patterns of Causality

Understanding a range of science concepts involves reasoning about forms of cause and effect that most students are unfamiliar with. Often when we think of causal patterns, we think of simple linear forms—where one thing directly makes another thing happen. But explanations are seldom so simple.

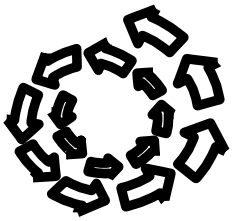


Linear Causality: One thing happen directly makes another thing happen. It can be thought of as a straight line between a cause and event. For example, a ball knocks a block over. Many events in the world seem to be examples of linear causality at a surface level of analysis, but are actually revealed to be more complex when further analyzed.

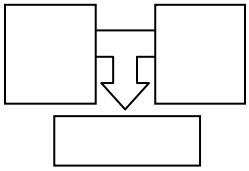
Domino Causality: One or more things happen, which then cause one or more other things to happen, which cause one or more other things to happen and so on. It works just like a branch of dominoes where one hits the next and then that effect causes the next one to fall and so on. For example, one person comes to school sick and s/he gets the teacher sick, then everyone has a sub. There may be more than one branch to the domino pattern. On another branch, her friend might get sick, might miss a sports event that s/he was looking forward to and so on…



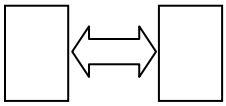
Cyclic Causality: Two or more things iteratively cause each other to happen. The events are connected in a circle. It can be as simple as one event makes another event happen and then the second event makes the first event happen again which then makes the second event happen again and so on. It's the classic chicken and egg problem. It often doesn't make sense to talk about which came first. An example from ecosystems is that plants grow and then die. Decomposers consume them and release the nutrients within the plant back into the soil affecting the growth of other plants.



Spiraling Causality: Some forms of cyclic causality involve escalation, amplification or in the opposite case, increased dampening. Each time it goes around, the level increases. For example, in the cafeteria, the person next to you talks to their friends a little louder so that he/she can be heard over your conversation with your friends, then you talk a little louder to your friends to be heard over the person sitting next to you, then they talk even a little louder to be heard over you, and so on. It can also involve de-escalation such as when a teacher talks softer and softer to get kids to listen more and more.



Relational Causality: In relational causality, a relationship between two things causes the outcome. For instance, you can't be an older sister or brother without having a sibling whose age is less than yours. It is the relationship between your ages that makes you older or younger than someone else. Another example is that objects don't just sink or float. It is the difference between the density of the object and the density of the liquid that the object is in which causes the outcome of sinking or floating.



Mutual Causality: Here, two things affect each other (though not necessarily in the same way). One event or process typically has an impact on both. The event might help both people (mutually beneficial) or it might help one at the expense of another (a thief stealing, for example). When a bee takes nectar from a flower, the flower also is pollinated creating a mutually beneficial outcome.

Teaching these causal patterns is a good way to help students recognize greater complexity where it exists and to have a vocabulary for talking about it. There are also certain default assumptions that students are likely to hold unless we help them to recognize these assumptions and to reason with greater complexity in cases where it better describes the dynamics.

Challenges in Reasoning About Causality

Research shows that we tend to make a set of simplifying assumptions about the nature of causality. These assumptions can distort many concepts in science learning and beyond. Here is a list of the assumptions that students make in contrast to more complex forms of causality:

Students tend to assume that causality is:	Example	Instead of:	Example
Linear	When I suck on the straw, I make the juice come up.	Nonlinear	I create less air pressure inside the straw than outside, so the imbalance results in the juice getting pushed up the straw.
Direct without intervening steps	Green plants matter to animals that eat them but not to animals that eat the ones that eat plants.	Indirect	If the green plants disappeared, it would eventually impact other organisms in the food web.
Unidirectional	Bees take nectar from flowers for their food.	Bi-directional or mutual	Bees take nectar from flowers for their food and they cross-pollinate the flowers resulting in the production of fruit.
Sequential with step-by-step processes	The electrons crowd onto the circuit going to each bulb. The first one gets power first.	Simultaneous	The electrons move like a bicycle chain turning in a circle all at once making the bulb light when it moves.
The result of obvious, perceptible characteristics	The object sinks because of its weight.	The result of non-obvious, imperceptible variables	Density, an intensive quantity, impacts sinking and floating.
Due to active or intentional agents	The electrons move to make static electricity.	Due to passive or unintentional causes.	Protons and electrons are attracted to each other. Seat belts passively cause us to stop when the car stops.
Event-based	If something happens I pay attention to it.	Due to steady states	Bridges stand because of balanced forces.
Deterministic; Effects always follow “causes”	I did it before and didn’t get sick, so it won’t make me sick.	Probabilistic	Getting sick depends upon many things. Even if I didn’t get sick before, I can still get sick now.

Spatially close to its effects	Satellites have a driving force in them.	Distant	The forward motion of the satellite and Earth's gravitational attraction result in a satellite's path.
Temporally close to its effects	I can't see any bad effects of getting a suntan right now.	Having a delay between cause(s) and effect(s)	The hurtful effects of getting a suntan accumulate and appear after a delay between cause and effect.
Due to the first cause that they identify	The boiling of the water is the result of the flame under the container. The writing on cemetery stones is hard to read because of the age of the stone.	Potentially the outcome of a different single cause (If there are multiple sufficient causes) of the outcome of multiple causes in combination	The boiling of the water is due to increasing the pressure in the container by reducing the volume. The writing on cemetery stones may have eroded due to combination of acid rain, physical abrasion, the softness of the stone, etc.
Centralized with few agents	The queen bee directs the activity in a beehive.	Decentralized with distributed agency and emergent effects	The behaviors and interactions of many bees result in an organized system.

How This Module is Set Up

This module is set up so that it has introductory lessons and review/transfer lessons. Lesson 1 introduces the need for reasoning about causal complexity. Lessons 2 and 3 introduce domino and cyclic causality as a means to contrast to simple linear causality and Lesson 4 asks students to analyze real world situations where these patterns are in play.

The module intentionally begins by introducing three that are fairly easy to grasp but also contrast with each other to offer a sense of the possibilities: linear, domino, and cyclic. Introducing more than one at once enables students to compare the three types in order to deepen their understanding through this comparison. It also serves as an introduction to multiple causal patterns.

Lessons 5, 6, and 7 introduce new forms of causal patterns: spiraling; mutual; and relational. Lesson 8 asks students to compare and analyze these patterns in real world contexts.

Teachers commonly ask at what age it is appropriate to introduce causal patterns. Research on children's understanding of causality suggests that they are learning about causal principles from the very earliest days of life. However, as far as learning to talk about causal patterns in a reflective sense, we have had good outcomes with some forms of causality (domino and cyclic causality, for instance) as young as first or second grade. We have also successfully engaged children as young as preschool in activities and games that encouraged them to investigate and think about different types of causal patterns. While the activities in the module are intended for middle school, some could be adapted for use with young children.

These lessons follow a conceptual change framework of learning where students are asked to reveal their current ideas about the nature of causality and then are given the opportunity to review and revise these ideas as they develop more sophisticated ones. The approach taken here is to allow students the opportunity to discover the patterns through scaffolded opportunities and discussion.

Instead of introducing the names of causal patterns first and then working with examples, the lessons are set up to introduce examples of each pattern first – without necessarily saying the pattern names. This offers students the opportunity to develop their own vocabulary for the patterns on their own. Even though students tend to reduce causal patterns to simple linear causality, research suggests that they have experience with and the ability to recognize a much broader set. Therefore, the lessons attempt to build upon students' existing causal knowledge. The names and descriptions that students come up with can become part of the "language of causality" in the classroom. Eventually, students will need to learn the causal vocabulary used in the Understandings of Consequence Project curriculum modules if they use these modules.

Lesson 1
Why Learn About Causality?

Understanding Goals

- Causality is about how and why things happen. We often talk about a "cause" and an "effect."
- We tend to simplify causality to one thing making another thing happen.
- However, often there is more than one cause and one effect.
- There can be different patterns of causality.
- When we simplify causality in a complex world, the results can be surprising!

Background Information

Why Learn About Causality?

This lesson is designed to introduce the concept of causality in general and to help students see that sometimes we simplify what happens in our live in simple cause and effects stories. These simple stories that we impose upon our experience don't always do the very best job capturing what is going on. The lesson introduces a number of real-life stories where the outcomes did not match what people expected.

In addition to helping students to think about how causality works in the real world, this lesson aims to help students see that they aren't the only ones that impose a simple linear causality on the world. It is a common human tendency—one that invites our reflection. Research shows that not all cultures are so inclined to impose simple, linear models. There is some research to suggest that some Asian cultures are more likely to notice relationships and other research to show that certain indigenous cultures view the world with more connectedness than other cultures.

Inviting Open-Ended Discussion

The lesson is designed to encourage the students to reflect upon what happened in the stories and to reach their own conclusions. Help the students to realize that these are not just mistakes of the past, rather these mistakes are still made today and they are made by all of us. Engage students in thinking about why such patterns might be common. Why might we fall into such patterns?

Lesson Plan

Materials

- Copies of the "Parachuting Cats into Borneo" Story
- Copies of newspaper account of effects of Hurricane Katrina locally:
- http://en.wikipedia.org/wiki/Effects of Hurricane_Katrina_in_New_Orleans and globally. On the economy http://www.bls.gov/opub/mlr/2007/06/art1exc.htm; And on oil production: http://www.cbsnews.com/stories/2005/08/30/national/main804787.shtml
- Copies of New York Times Opinion column, on effects of diverting grain for fuel http://www.nytimes.com/2007/09/19/opinion/19iht-edethanol.1.7567074.html
- Chart paper or board
- Paper for students to draw on

Prep Step

- Review the lesson plan, background information, and understanding goals.
- Download and prepare copies of newspaper articles

Step 1: What is Causality?

Explain that "causality" means having to do with causes and their effects. Often when people think about causality, they think about cause and effect in this way: *this makes that happen*. It's direct. It's simple—cause and effect.

Write "this" and "that" on a chalkboard, and draw a line connecting the two words, leaving room below for many more examples. Explain what you have written, and that the line indicates that "this" makes "that" happen.

Above the word "this," write "cause;" above the word "that" write "effect." Draw a line connecting the two words. Explain that this shows that a "cause" makes an "effect" happen.

Under "this," write "ball knocks into pin." Under the line, draw another line. Under "that" write "pin falls over." Explain again that the arrow indicates that the "ball knocks into pin" *makes* the "pin falls over." Point out how this is direct, simple, and has only two-steps: *this makes that happen*.

Ask students for more examples. Gather ideas, write them on the board and connect them where appropriate.

If students have difficulties generating ideas, here are some examples which can be used to get them going. Try not to use all of these examples – students should do the idea-generating!

Cause	Effect
Stubbed your toe on the door	toe hurts
Didn't eat breakfast	felt very hungry at lunchtime
Drank too much water	had to go to the bathroom
Did your chores when you were supposed to	received your allowance
Shut your eyelids	could not see

In the rest of this lesson, we'll see why simple linear causality isn't always the best way to think about causality.

Step 2: A Problem in Borneo

Pose the following problem to the students.

Health officials were dealing with an outbreak of malaria, a potentially fatal disease in a country called Borneo. Malaria is transmitted by mosquitoes through their bites. What are some things that you think the officials should do?

Collect the students' ideas. List them on the board. Ask, "Is any other information that you would like to know before you make your decision about what to do?"

Explain to the students that the Borneo story is a true story of something that happened about forty years ago. Read the story together and discuss it.

Ask,
Did anything surprise you about what happened?
What did the World Health Organization do that they should not have done?
What information would they have needed to anticipate the effects?
What pattern would describe the events?

Have the students reread the story to themselves. Have them draw an "impact diagram" showing what happened. An "impact diagram" uses lines and arrows to show direction of impact. It can also use bigger darker arrows to suggest magnitude of impact. Circulate to see what they have drawn to make sure that they understand what happened.

Go back and look at the patterns of their proposed solutions. What assumptions does each make about the nature of the causal patterns involved? Contrast their expectations and those of the World Health Organization to what actually happened.

Introduce the words, "unintended effects." What did the World Health Organization intend to do? What did they do instead? Why did this happened? Contrast the words "intended effects" to "unanticipated and unintended effects." How is the emphasis of the terms different?

There is a saying, "Hindsight is always 20/20." What do they think it means? It can be very hard to predict what will happen in a given instance because you cannot know which factors will be relevant and which will not. When we use hindsight, we often think that we would have been able to predict outcomes that we could not have prior to the outcome. After something happens we know which factors and events

are important. Beforehand, we do not know how to weigh different aspects of the problem.

However, we can think about possible outcomes and realize that things are often more complicated than they seem. We can push beyond our first assumptions and be careful not to simplify complex patterns.

Can they think of any other events like the Borneo Story? Other examples include the introduction of the mongoose into the Hawaiian Islands and the introduction of invasive plants such as Purple Loose-strife and Oriental Bittersweet into gardens. List their ideas on the board. Note how many of their examples are about ecological systems. We often do not understand the ecological complexity of our world very well. But as they shall see, there are examples from many other areas of life as well.

Step 3: Considering What Happened During Hurricane Katrina

Next pass out and discuss the newspaper articles about Hurricane Katrina. Hurricane Katrina was a natural disaster, but planning was completely inadequate.

Again, have students draw "impact diagrams" showing the causes and effects of what happened. Then have students meet in small groups of three to compare their diagrams and discuss what they each think happened. Encourage them to modify their diagram based on what they learn from their classmates.

Discuss what happened as a group. What were the "unanticipated effects" of Hurricane Katrina?

Step 4: Considering What Happened When Grain Was Diverted for Fuel

Have your students read the opinion piece from the New York Times on diverting grain for fuel. Discuss it as a group. What is the writer arguing? What might the opposite perspective look like? Have the students help you draw an "impact diagram" of what the writer is predicting on the board. What were the "unanticipated and unintended consequences" of diverting grain for fuel? Consider the short term and long term differences. How might they differ? If some are good and some are bad, what do they think should be done? Is the problem "using grain for fuel" or "how humans planned how to use grain for fuel"?

If there is time, invite the class to debate both sides of the case. They will need to do some background research first. Be sure to discuss how difficult it can be to predict outcomes. We can look back on "what has happened" with the benefits of 20/20 hindsight. But forecasting outcomes is far more difficult.

Step 5: Step Back for Reflection

Step back to consider the three stories as a whole. What did they learn from comparing them? What big lessons can they take away from this lesson? Collect their ideas on the board. [*Students may say things like, "things are seldom as straightforward and simple as we think" or ""effects can cause new effects and so on" or "the words cause and effect are misleading because there can be a lot of effects and even a lot of causes."*]

Step 6: Connecting Forward

Ask them to keep their eyes out for other examples like this. It can be something that they see in the newspaper or on television or something that happens to them. In each case, ask them to think about why what happened occurred. Were there unanticipated or unintended consequences? If so, why were they unanticipated or unintended?

Parachuting Cats Into Borneo[3]

In the early 1950s, there was an outbreak of a serious disease called malaria among the Dayak people in Borneo. The World Health Organization tried to solve the problem. They sprayed large amounts of a chemical called DDT to kill the mosquitoes that carried the malaria. The mosquitoes died and there was less malaria. That was good. However, there were side effects. One of the first effects was that the roofs of people's houses began to fall down on their heads. It turned out that the DDT was also killing a parasitic wasp that ate thatch-eating caterpillars. Without the wasps to eat them, there were more and more thatch-eating caterpillars. Worse than that, the insects that died from being poisoned by DDT were eaten by gecko lizards, which were then eaten by cats. The cats started to die, the rats flourished, and the people were threatened by outbreaks of two new serious diseases carried by the rats, sylvatic plague and typhus. To cope with these problems, which it had itself created, the World Health Organization had to parachute live cats into Borneo.

Lesson 2
Learning About Domino Causality

Understanding Goals

- Simple linear causality refers to when one thing directly makes another thing happen.
- Domino causality refers to extended linear causality where a cause results in one or more effects that, in turn, result in new effects.
- Domino causality has direct (because it includes simple linear causality) and indirect effects.
- Domino Causality can have far-reaching effects.
- Domino Causality can have a radiating structure where there are many direct outcomes and each of these might lead to indirect outcomes.
- Domino Causality can have a branch-like structure where events closer to the "stem" impact more of the system than events in the "twigs."

Background Information

Comparing Simple Linear to Domino Causality

This lesson compares simple linear causality to domino forms of causality. In domino causality, there can be indirect effects of an effect that extend beyond the direct (and often, intended) effects. Many events in life are characterized better by domino-like patterns than simple, linear, direct patterns. We see references all the time to "side effects;" "collateral damage;" and "additional benefits" and use sayings like, "one thing led to another." However, in everyday life, we tend to be focused on the moment, what is in front of us and often—being efficient. We don't always stop to trace out extended effects.

The Features of Domino Causality

This lesson contrasts the features of simple linear causality (like a line; one thing makes another thing happen; simple, short; and the cause leads directly to an effect) to domino causality (like dominoes; not as simple, longer; effect becomes a cause becomes an effect becomes a cause…; can be a line or radiating or branching; and it has an end and a beginning).

Thinking about the features of domino causality can help us when we are reasoning about solutions to problems. If we set patterns of causes and effects in motion, it is important to anticipate where those effects may "end up." Reasoning about domino causality can also help us think about where we focus our energy in terms of solutions—getting at the "root cause" or tracing impacts closer to the stem to get at initial causes prevents treating symptoms only.

Using Stories to Discover Causal Patterns

This lesson (and some of the others) uses children's books to introduce causal patterns. Teachers who have worked with us over the years have helped us to compile a list of stories and these are available in the reinforcement section at the end of the module.

Lesson Plan

Materials

- Journals or white, unlined paper
- Chart paper or board
- Resource Sheet on Simple Linear Causality
- Resource Sheet on Domino Causality
- Book: Because Brian Hugged His Mother by David L. Rice.
- Book: The Lorax by Dr. Seuss
- Set of dominoes

Prep Step

- Review the lesson plan, background information, and understanding goals.
- Gather the books and materials.

Step 1: Reflecting on Examples of Unanticipated Effects

Reflect with the class on the examples that they discussed in the last lesson and any additional ones that they found on their own. In each case, how did the expectations of those involved differ from the outcome? Remind the class of the understanding goals from the last class and surface the big ideas from the examples that they share.

Step 2: The Features of Simple Linear Causality

Introduce the idea that we often think of causality as a simple linear, "this made that happen." [*Note to Teacher: With younger children, you might want to call these "causal stories" instead of using the word "causality."*]

Ask the students to describe this kind of causality and track their ideas on the board. Then hand out the resource sheet on simple linear causality and discuss it together as a group.

In general, simple linear causality is:

- like a line
- one thing makes another thing happen
- simple, short
- cause leads directly to an effect

Step 3: Introducing Domino Causality

Without announcing what kind of causality is involved, read the story, Because Brian Hugged His Mother. Ask the students what causal patterns they can find in the story. *Most students will realize that there is a clear domino pattern. There is also a cyclic aspect at the end as the kindness comes back to Brian. Students might also talk about "what goes around comes around" or the idea that you can "pay it forward."*

As students begin to talk about it as domino-like, set up a row of dominoes.

Ask:
"In what ways is what happened just like pushing over a row of dominoes?" Collect ideas. *(One thing makes another thing happen. The effect becomes the cause of something else. Brian's mother feeling happy was a direct effect of his hugging her but then the hug had indirect effects, too and so on.)*
"In what ways is what happened not just like pushing over a row of dominoes?" *(Each thing in the dominoes is the same—a domino knocks over another domino. Each thing in the story makes something different happen. The dominoes have a clear ending, the story has a circle at the end and so on.)*

Next, read the story, The Lorax, by Dr. Seuss. In the book, the Once-ler recounts to a little boy the story of a forest of Truffula Trees that stood at the spot where they are standing and the many creatures that lived there. The Once-ler chopped down the trees (to make Thneeds, an odd-looking garment that he insisted "everyone needs)." Despite the protests of a creature called the Lorax, the Once-ler kept chopping the trees. The brown Barbaloots who lived on the fruit of the tree had to leave. The pond got polluted and the humming-fish had to leave. The skies gradually grew darker and more polluted and the swans had to leave. Eventually all of the Onceler's family also left and finally, the Lorax did, too.

Ask,
"In what ways is what happened just like pushing over a row of dominoes?" Collect ideas. *(One thing makes another thing happen. The effect becomes the cause of something else. The chopping of trees leads to less fruit which leads to hungry brown Barbaloots.)*
"In what ways is what happened not just like pushing over a row of dominoes?" *(Each thing in the dominoes is the same—a domino knocks over another domino. Each thing in the story makes something different happen. Also, there are many radiating effects in the story. Producing thneeds leads to many effects directly and indirectly.)*

Note to Teacher; The reason for reading a second story with the same deep structure but different surface features is that it helps the students to discern what is similar about them—the deep structure.

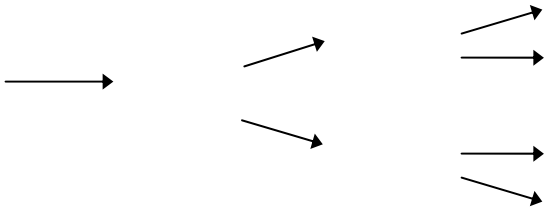
Step 4: Domino Causality in Depth: Features and Variations

Ask the students to generate a list of the features of domino causality with you. In general, domino causality is:

- like dominoes
- not as simple, longer
- effect becomes a cause becomes an effect becomes a cause…
- can be a line or radiating/branching
- has an end and a beginning

Branching Domino Causality:

Discuss different variations on Domino Causality. Set the dominoes up in a branching pattern. Ask the students to offer examples that might work like the branching version.



What if the end effects of the branch were bad (people got sick, there was environmental damage and so on…)? What strategies would work best for quelling the damage? [*The closer to the stem that you can stop the damage, the less you will be treating symptoms rather than root causes.*]

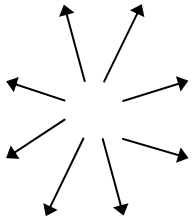
What if the end effects of the branch were good (it made people happy as in the story above or it improved people's health, and so on…)? How does this effect how you think about the branching structure? [*The branch is a way of spreading good effects and multiplying the impact of one good deed.]*

Compare their examples to the branch of a tree. If a tree has a disease, if it is in the twigs, you probably would search back to where the tree is healthy (perhaps along a branch and treat the tree at that level.) If the disease is "systemic"—meaning closer to the stem or roots, you would need to treat it at that level.

If a tree is chopped down, it impacts everything along the tree. If a twig or branch is broken off, it impacts from that point outwards typically. Intuitively, we know this. [*Unless a disease gets into the tree at that spot because the tree is "open to infection." This is where the analogy "breaks down."*]

Radiating Domino Causality:

Discuss another variation on Domino Causality. Set the dominoes up in a radiating pattern. Ask the students to offer examples that might work like the radiating version.



What if the end effects of the radiating version were bad (people got sick, there was environmental damage and so on…)? What strategies would work best for quelling the damage? [*The central cause must be addressed because it initiates everything.*]

What if the end effects of the radiating pattern were good (it made people happy as in the story above or it improved people's health, and so on…)? How does this effect how you think about the radiating structure? [*In this case, we would want to encourage the central cause because it directly leads to such good outcomes for so many. We would be more likely to notice the connection of the good outcomes to the precipitating event than in a branching domino structure.*]

Have students read the resource sheet on domino causality and work on generating some examples. Give them an opportunity to ask questions of clarification. Working with a partner to generate examples may help to facilitate the brainstorm process.

Step 5: What is Hard About Domino Causality?/Connecting Forward

Ask students to consider why people often miss domino causality. Ask them to each generate at least two ideas and write them on their sheet or in their journals. Collect their ideas and make a list on the board. Here are the kinds of things that people typically say:

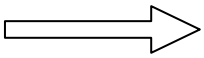
-You might not know that one thing is connected to another (like in the Borneo story.)
-You may not have traced out the links because you were in a hurry or just didn't think of it.
-If you get one link wrong, you may have traced out the rest of the links differently.
-Some of the links might take a long time to show up. You might never even know that the link exists because you stopped paying attention.
-Some links may happen far away and you may have no way of knowing that the thing happened or was connected to what you did.
-People have a fairly short attention span. They may not keep paying attention.
-People tend to notice dramatic effects but not more minor ones that can lead to bigger ones.

Ask the students to give themselves one piece of advice to help them think about domino causality and to try to keep it in mind when they live in the world. [*Note to Teacher: You can come back to this later in the year and ask them if they are using their advice and what puzzles the advice presents.*]

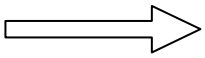
Simple Linear Causal Pattern

"Causality" means having to do with cause and effect. Using words that involve causality helps us understand and describe how things happen. Scientific thinking often involves trying to understand how things happen, so using words that involve causality can help us understand things in a scientific way.

"Linear" means "in a straight line." In linear causality, we say that one thing directly made another thing happen. You can draw a straight line (or a one-way arrow) between the two things to show that one thing caused another thing to happen.



Here is an example. "The ball knocked the pin over."

ball knocks into pin  **pin falls over**

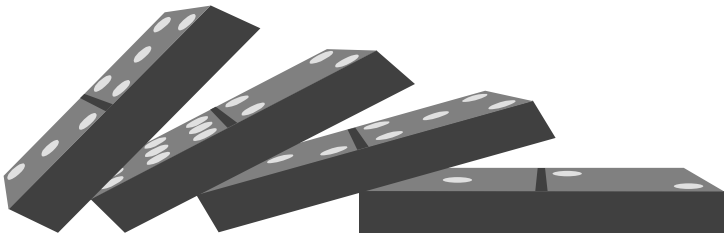
Simple linear causal pattern means that there is only one connection. One thing leads to another and the effects stop there.

Can you think of examples where simple linear causal patterns are in play?

Domino Causal Patterns

"Causality" means having to do with cause and effect. Using words that involve causality helps us understand and describe how things happen. Scientific thinking often involves trying to understand how things happen, so using words that involve causality can help us understand things in a scientific way.

"Domino causality" works like dominoes! In dominoes, a cause results in an effect, and the effect becomes a cause for a new effect, and so on.



Also, dominoes can have branches: one domino can fall and knock into two (or more!) dominoes, which makes those two (or more) dominoes fall; those two (or more) dominoes knock into other dominoes, and so on. In other words, one cause can have two (or more) effects, and each of those effects become causes for new effects, and so on.

Here is an example of domino causality.

Mike comes to school with a sniffle. He works closely on a class project with PJ. In a few days, Mike has a bad cold and is home in bed. A few days later, PJ is playing in a basketball game. He feels miserable and keeps missing shots. Finally the coach takes him out and puts Tobi in who has been sitting on the bench all season. Tobi plays really well and his friends and parents are thrilled. But it is too little too late and PJ's team loses the game. The next day, PJ comes down with a bad cold, too, and ends up home in bed.

Draw a diagram of the domino causal connections in this story.

Can you think of other examples of domino causality?

Lesson 3
Learning About Cyclic Causality

Understanding Goals

- Simple linear causality refers to when one thing directly makes another thing happen.
- Domino causality refers to extended linear causality where a cause results in one or more effects that, in turn, result in new effects. Domino causality has direct and indirect effects. It can have far-reaching effects.
- Cyclic Causality is like a circle. Cause A results in Effect B which also acts as Cause B which, in turn, precipitates Effect/Cause A and so on. So causes become effects and vice versa. It often does not have a clear beginning, middle or ending, once it has started.

Background Information

What is Cyclic Causality?

Students often have an opportunity to think about cycles. For instance, they might learn about the water cycle or the seasons. Some cycles are just that, cycles of events that happen in a given, repeating order—for instance, the seasons. Other cycles have an inherent cyclic causality where one thing makes another thing happen in a repeating pattern. For example, think about a home thermostat. As a room starts to cool off, the thermostat reaches a certain point and that causes the heat to come on, soon the room warms, and the thermostat switches the heat off. As the room cools, the thermostat turns the heat back on again, in a cycle that repeats again and again.

In cases of cyclic causality:

- There may be no clear beginning or ending.
- A cause can also be an effect and vice versa.
- Feedback may perpetuate the cycle.
- A impacts B impacts C and so on, and eventually impacts A again.
- There is an inherent repeating pattern.
- The pattern is often sequential, but it is possible to have simultaneous cases.

Cyclic causality is best characterized in the sayings, “What goes around comes around” or “Which came first, the chicken or the egg?” Breaking a circle into linear parts loses essential elements of the inherent causality. However, research shows that students often break cyclic causality into simple linear patterns. When learning about simple circuits, students are taught that the circuit is a circle and that it must be

closed, however, many of them still revert back to explanations where one wire brings something to the bulb and the other is a ground.[1] When reasoning about decay, students often start with an organism as the beginning of the process, obscuring the earlier process of matter recycling that makes up that organism.

Cyclic causality is an essential component of deep understanding of many science concepts—the water cycle, the rock cycle, matter recycling, and so on. In ecosystems, plants grow and then die. Decomposers consume them and release the nutrients within the plant back into the soil affecting the growth of other plants. Convection currents entail cyclic causality. Climate change involves many positive feedback loops, where one event triggers other events that feed back into the cause of the initial event, introducing further complexity into understanding and reasoning well about climate change solutions. There can also be multiple feedback loops in operation at the same time.

Not all cycles involve cyclic causality. The seasons are a cycle but one does not cause the other. The processes within the cycle have to have a causal relationship to what happens at the next node of the cycle.

Additional Resources for Cyclic Causality

The following books have an embedded cyclic causality that can jumpstart a nice discussion with students and can help to reinforce the understanding goals in this lesson. There are also many stories that have a cyclic causal pattern that also include escalation (For instance, Dr. Seuss's The Butter Battle Book). These will be the focus of a later lesson. The books here involve cyclic causality without escalation.

If You Give a Mouse A Cookie or If You Give A Moose a Muffin or If You Give a Pig a Pancake by Laura Numeroff
-What kind of causality is central to each of these books?
-How does the cycle start again?
-How is this type of cyclic causality different from the feedback loop in a home heating system or other types that have a central mechanism that influences the feedback (Note to Teachers: *The iterative nature is specific to each behavior rather than being centrally driven. You could imagine that at any point the pattern might diverge from the cyclic pattern.*)

Boy, Frog, and Dog (A picture book by Mercer Mayer)
-What type of causality is central to this story?
-One possibility is to have the students set the pictures in this book out in a circle. Does it work to set it out and not have a beginning and an ending?

Lesson Plan

Materials

- Journals or white, unlined paper
- Chart paper or board
- Resource Sheet on Cyclic Causality

Prep Step

- Review the lesson plan, background information, and understanding goals.

Step 1: Connecting Back

Ask the students what examples of simple linear and domino causality they noticed since the last lesson. What made each one a simple linear or domino causality? What variations did they notice in each pattern?

Step 2: Analyzing the Causal Patterns in Three Examples

Ask the students to analyze the examples on the sheet for this lesson. It introduces three examples: a home heating system; a social example; and the process of decay. Students should compare what is going on and draw a diagram to show how they think each system behaves and what the causal pattern is like. This is a good activity to do in small groups.

Step 3: Analyzing the Causal Patterns In and Across the Examples

As a group, discuss what the students came up with. Make a list on the board of the features of each example, collecting ideas from the students. Then compare the examples looking for similarities and differences between them.

Home Heating System Social Issue Decay

Discuss the features that the students came up with for each example.

Ask:
"What overlaps and what differences do you notice?"
"What names might you use to describe this type of causality?"

Discuss the features that stand out across the examples.

In each example, the causal pattern…

- Is like a circle
- Cause A results in Effect B which acts as Cause B which in turn precipitates Effect/Cause A and so on. So causes become effects and vice versa.
- May have no clear ending or beginning

Explain that this can be called “cyclic causality.”

Read and discuss the resource sheet on cyclic causality. Have the students think of an example of their own.

Step 4: What are Some Things that Make Cyclic Causality Tricky?

Ask the students to consider what they find easy and difficult to think about when reasoning about cyclic causality. Here are some of the kinds of things that the class might discuss:

-It is hard to stop!
-It is like a chicken and egg problem—sometimes you don’t know why it got started.
-We don’t have good words in our language for talking about things that are cyclic.

Step 5: Connecting Forward: Looking for Examples of Cyclic Causality

Ask the students to keep track of any cyclic causal patterns that they notice over the next week or so. Encourage them to attend to social issues, news stories, literature, science, and so on. In other words, encourage them to look broadly across many domains.

Name _____ Date _____

Analyzing the Causal Pattern in Three Examples

1. On a cold winter's day, the thermostat is set to 68 degrees. When the temperature drops below 66 degrees, the thermostat on the wall switches the boiler on and a heater near the floor comes on. After the temperature reaches 68 degrees, the thermostat switches the boiler off and the heater goes off. What patterns are involved in this causal system and how would you describe why/how it works?

2. Zack's mom gets mad because Zack spends so much time in his room. She gets annoyed at him and stops talking to him as much. Zack senses her anger and retreats to his room. His mom feels more distant from him and yells at him for not helping with things around the house. Zack gets away from her yelling by hiding out in his room. Because he is in his room, he doesn't notice things around the house that he could help with. What patterns are involved in this causal system and how would you describe why/how it works?

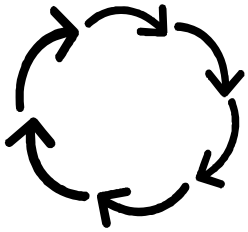
3. An apple falls from a tree in an orchard. It sits on the ground and is slowly devoured by insects, worms, and microbes. After a short while the apple appears shriveled and rotten. Eventually the apple appears to be gone but the particles that made up the apple are part of the soil now and the nutrients and matter are taken up by the plants in the orchard, including the old tree that the apple originally grew on. What patterns are involved in this causal system and how would you describe why/how it works?

What is Cyclic Causality?

Cyclic causality means that events are connected in a circle. One event (or process) makes a second event (or process) happen but the second one then makes the first one happen again (which then makes the second one happen again and so on). There can be more than two events or processes in the circle.

In a cyclic cause and effect story:

- There is no real beginning or ending (once it gets going).
- A cause can also be an effect and vice versa.
- If you break the story into a line, it loses important parts of the story.



Cyclic causality happens in science and in everyday life. For instance, if you say something that hurts your friend's feelings, then she might not be nice to you, so you get mad and aren't nice to her, so then she is not nice to you, and so on. It becomes a cyclic cause and effect story.

Try to come up with an example of a cyclic causal story of your own. Draw the cycle below and explain how each event or process causes the next and eventually feeds back to the first event or process. Use arrows to show what makes what happen. Then check your diagram to make sure it shows cyclic causality.

Lesson 4
Causality in Everyday Life

Understanding Goals

- Simple linear causality refers to when one thing directly makes another thing happen.
- There are causal patterns that are more complex than simple linear causality.
- Domino causality refers to extended linear causality where a cause results in one or more effects that, in turn, result in new effects. Domino causality has direct and indirect effects. It can have far-reaching effects.
- Cyclic Causality is like a circle. Cause A results in Effect B which acts as Cause B which, in turn, precipitates Effect/Cause A and so on. So causes become effects and vice versa. It often does not have a clear beginning, middle or ending, one it has started.
- Noticing different causal patterns in everyday life means that we need to figure out their features without knowing in advance what type of causality is in play.

Background Information

Reinforcing the Causal Patterns

This lesson reinforces the three causal patterns considered in the previous two lessons. It aims to help students become familiar with the idea of multiple causal patterns and to help them realize that there are multiple patterns in the world. Discerning those patterns in everyday contexts and in contrast to each other deepens their understanding of the causal features of each. Some of the videos offer science examples (for instance, an apple rotting or moth flying towards a light) to compare to the everyday examples.

Analyzing video examples of causality in the real world also helps students to discern the causal patterns despite nuances in the real world contexts. For example, in some instances of domino causality, each event is essentially the same (a domino falling) and in some instances, each event is caused by the one before it but has different characteristics than the one before it. It can also help students differentiate between structures that are and are not examples of types of causality. For instance, a gerbil spinning in a wheel might bring to mind a cyclic pattern because the wheel turns in a circle, but this does not necessarily make it a cyclic causality.

Many of our collaborating teachers have used these videos with their classes. Here is some of their advice for making it work well with your class!

- Don't treat the videos as though they have right answers. Ask the students to tell you what patterns they see and what makes them think that. Depending upon what level they are analyzing the patterns at, different patterns make sense.

- Give all of your students think time before discussing each pattern. You can have them jot their ideas on paper or make up an activity sheet to put their ideas on.

- Some of us went over each type of pattern or handed out a sheet first and had the students match them. Others had the students talk about what happened and what it was like and then named the causal pattern. The second way invites more ambiguity, but also deeper processing. Either way can work well depending upon your students.

- Some of my students found it easiest to draw the patterns first and then think about what they might call them.

- Encourage students to compare the videos to what they see in the real world. This helps them to begin seeing the causal patterns all around them.

- Try to get students to focus on the features of what makes a certain scene a certain kind of causal pattern. This will help you detect confusions between different causal patterns.

- The causal patterns can work together, so students might notice more than one type in one video.

- My students made up names for some of the patterns that they saw and we used these in our classes. Help them think about causal patterns in the world, not to memorize a certain set. For instance, my students chose the name "spiraling causality" instead of "escalating causality" because escalating only goes up, not down.

- If you compare two different videos, show them each multiple times and make some notes on the board to help students hold the ideas in their heads to compare them. Otherwise, it can be too much information at once!

- Get students to be as specific as possible to help you analyze confusions. For instance, if a student says, "In relational causality, you have to have two things," encourage them to say more. Are they focusing on comparing the two things as in a relationship? Or just adding the two things together?

- Watch the same video a number of times in one sitting and see how students' ideas deepen and change.

- Watch the videos during different points in the year and see if students' ideas deepen and change.

- Later in the year, you can try having students create their own videos. It will help them to transfer the concepts and will tell you a lot about how they understand the different patterns.

- Listen carefully to how your students talk about each pattern. Try to discern confusions in their thinking between the different patterns.

Lesson Plan

Materials

- Journals or white, unlined paper
- Chart paper or board
- Video clips of causality: billiards; moth to light; dominoes; conduction; convection currents in a lava lamp; and apple decaying downloadable from the *Causal Patterns in Science* website: http://www.cfa.harvard.edu/smg/Website/UCP/causal/causal_examples.html

Prep Step

- Review the lesson plan, background information, and understanding goals.

Step 1: Thinking About Current Conceptions

Remind the students about what they learned in the first few lessons—that sometimes causal patterns are more complex than they at first appear and about a number of different causal patterns (linear, domino, and cyclic). Ask the students to write down their ideas about the features of each in their journals. After each student has had a chance to reflect upon their ideas, discuss the features as a group. Gather any examples that students have found of each type of causality.

Step 2: Analyzing the Causality in Video clips

Explain that in this lesson, we will be looking at some videotaped examples of things that happen and will talk about the patterns involved. Don't preface the patterns—let the students decide what they think each one is.

Show the first video clip of billiards on a billiard table. Before discussing it as a class, ask the students to draw a diagram of what they think is happening. Then ask:

"How would you describe the causal pattern involved in what is going on in the video?"

Ask the students to draw a diagram for the causal patterns that they found in each video. You might want to introduce the convention of using boxes and arrows to show events and causal connections between them.

Write billiards in the corner of the board and keep track of the phrases that the students use to explain the pattern.

Note to Teacher: These phrases are important aspects of building a causal vocabulary in your classroom. The names of the causal patterns in this module come from classroom conversations just like this one. Your students may find better ways to describe the causal patterns—ones that resonate well with their own experience.

Discuss the different diagrams that students came up with. One way to organize this discussion is to have a couple of students draw diagrams for the same example on one part of the board, a few others draw diagrams for a different example on another part of the board, and so on. This will allow you to look for similarities in how one example was depicted. Then you can look for differences in how it was depicted and discuss what diagrams/conventions/etc. they think works well.

Show each video clip and discuss it. Then contrast the videos and the diagrams as a whole. What was happening in each video clip? How were the videos similar? How were they different? Gather ideas.

For each example, have the students draw a diagram and discuss the similarities and differences in how students depicted it and the differences. Process what conventions worked well. After going through each example in this way, then compare the three types of causality involved.

Here are some sample comments about each clip:

Video #1: Billiards

"One thing makes another thing happen which makes another thing happen and so on…"
"This could be simple linear causality—the cue hits the black ball and makes it move."
"In the beginning, it hits the white ball which hits all the balls, so that it is more domino-like, or even a branching or radiating kind of domino."

Video #2: Moth to Light

"This seems like simple linear causality—the moth sees the light and goes right to it."
"One thing makes another thing happen."

Video #3: Dominoes

"This is domino causality."
"There are direct and indirect effects of knocking the first domino over."
"Sometimes we know that each domino will fall over and sometimes we don't."

Video #4: Conduction

"It spreads down the wire kind of like it is flowing—I guess it is domino-like."
"It shows conduction and that means that as each molecule gets heated up and starts moving faster, it bumps others and they move faster and heat is transferred down the wire."

[Note to Teacher: Most students will not see this as domino-like if they have not yet learned about conduction. In that case, you may need to explain it to students.]

Video #5: Lava Lamp

"The yellow stuff rises as it gets hotter and falls as it gets cooler and the cycle keeps going. It must be cyclic causality"
"It could be relational causality because the liquid sinks or floats in relation to the liquid it is in."
[Note to Teacher: Most students will not see this as cyclic if they have not yet learned about convection. They will also be unlikely to see it as relational if they have not studied density.]

Video #6: Apple Rotting

"Decay is a cyclic causality. The matter becomes part of the soil again.
"Plants growing will use the nutrients that are a part of the soil—so parts of the old apple."

Listen carefully to how your students talk about each pattern. Try to discern confusions in their thinking between the different patterns.

Step 3: Thinking About Key Features of Causal Patterns

Have students compare the features of their diagrams and the video examples. How were they similar? How were they different? Hopefully the students will have noticed the following features in their discussions above. Be sure to discuss these features explicitly.

Linear
- like a line
- one thing makes another thing happen
- simple, short
- cause leads directly to an effect

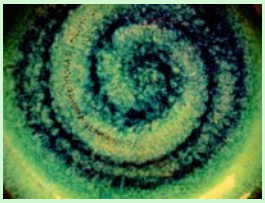
Domino
- like dominoes
- not as simple, longer
- effect becomes a cause becomes an effect becomes a cause…
- can be a line or radiating/branching
- has an end and a beginning

Cyclic
- like a circle
- Cause A results in Effect B which acts as Cause B which in turn precipitates Effect/Cause A and so on. So causes become effects and vice versa.
- May have no clear ending or beginning
- like a circle

Draw their attention to any terminology that they came up with during class that might work better or as well. Decide as a class how to refer to the different types.

Step 4: Making Real World Connections- Individual Work/Homework

As a class, come up with new, real-world examples for each type of causality. Think of real-world examples that could be described by the different causal forms. Encourage the students to generate two examples for each type.



Lesson 5
Learning About Spiraling Causality

Understanding Goals

- Spiraling causality (or escalating causality) is a form of cyclic causality.
- In some instances, with each turn of the cycle, the level of the effects increases. In other instances, with each turn of the cycle, the level of the effects decreases.
- Spiraling causality can result in outcomes at a dramatically different level than the original precipitating event, so it is often important to recognize the pattern early.

Background Information

What is Spiraling Causality?

Spiraling or escalating causality is one that many of us have experienced and one that we can relate to strong emotions. It is often associated with anger (road rage, increasing withdrawal, etc.) but can also be associated with lighter emotions such as increasing goofiness. Because the magnitude of effects can increase (or decrease) rapidly, it is important to recognize the pattern of spiraling or escalating causality. In these lessons, the terms "spiraling" and "escalating" are used interchangeably.

The features of spiraling causality include:

- A cyclic causality that has a feedback loop so that in each turn of the cycle, the causes and effects are increased or decreased (intensified or de-amplified).
- The amount or rate of escalation can increase (in addition to the increasing of the causes and effects).
- Cause A results in Effect B which acts as Cause B which, in turn, precipitates Effect/Cause A and so on. So causes become effects and vice versa.
- It is sequential as each event is a reaction to the one before it
- Often a clear beginning and ending, but not always.
- It is difficult to anticipate outcomes of later feedback loops during earlier feedback

What Experiences with Spiraling Causality Might Students Have?

Despite the complexity of spiraling causality, students often have had many experiences with escalating causality to draw upon. This includes experiences in the cafeteria where each student, in an attempt to be heard by those nearby talks a little louder and then other students talk a little louder in response, and so on resulting in

escalating noise. Many students will relate to having been in an escalating conflict with a friend and how quickly things can get out of hand.

There are many experiences in literature that relate to spiraling or escalating causality. The Butter Battle Book by Dr. Seuss is a good example. In it, the Zooks and the Yooks engage in escalating conflict because one population butters its bread butter side down and the other butters it butter side up. The parallels to the Cold War and other real world conflicts can lead to important discussion and consideration of the dynamics of escalation.

Lesson Plan

Materials

- Journals or white, unlined paper
- Chart paper or board
- Book: The Butter Battle Book by Dr. Seuss

Prep Step

- Review the lesson plan, background information, and understanding goals.

Step 1: Thinking About Current Conceptions

Ask the students to list experiences with cyclic causality. Typically, they will list ones that are pure forms of cyclic causality as well as some that involve escalation or spiraling. As they offer ideas, list those with escalating features separately from the ones with cyclic patterns.

Examples of purely cyclic patterns include text messaging such that each time the person you text receives a message, they respond and send one and so on; playing a game of catch; a conversation between two people, etc.

Examples of Spiraling Causality:
-The more you turn your music up, the more your mom yells, the more you turn it up…
-The more the brother pesters his sister, the more response he gets, the more he pesters her…
-The louder the person next to you talks in the cafeteria, the louder you have to talk, the louder he has to talk…

Step 2: Exploring Spiraling Causality

Read Dr. Seuss's book, The Butter Battle Book. Some of the students will have heard it before. As you are reading, about a third of the way through, stop and ask the students to reflect upon the following question:

What are the Zooks and the Yooks fighting over?

Ask the students to draw a diagram of what happens in their first few interactions. After about ten minutes, have a few students share their diagrams.

Continue reading. About two thirds of the way through the book, stop again. Ask students to reflect upon the following question:

What do you notice about the intensity of their interactions over time?

Again, ask the students to draw a diagram of what happens in their first few interactions. After about ten minutes, have a few students share their diagrams.

Step 3: Spiraling Causality in Depth: Features and Variations

Ask the students to consider what type of causality is in play. How would they describe it? What features does it have? How is this similar to and different from cyclic causality?

Spiraling Causality has the following features:

- One thing impacts another which, in turn, impacts the first thing (or alternatively impacts something else which then impacts something else and so on, but eventually impacts the first thing) with amplification or de-amplification of effects
- Involves feedback loops
- It is sequential as each event is a reaction to the one before it
- Often a clear beginning and ending

Why is it hard to think about well? It can be difficult to anticipate outcomes of later feedback loops during earlier feedback

What are some examples of this type of causality in the real world? List as many as they can think of.

Step 4: Deepening Understanding

Have the students write a story with escalating causality as its narrative and plot structure. Have them reflect upon what they need to include as features of spiraling causality before they start. Afterwards, encourage them to share their stories. For each one, analyze the features that contribute to the escalating causal patterns.

At another time, have them try writing a story with de-escalation as its narrative and plot structure. There are some very different challenges here in making the story work. Ask, “How did this force you to think differently than in the escalation story?” Encourage them to share their stories. For each one, analyze the features that contribute to the de-escalating causal patterns.

Step 5: Making Connections

In the coming weeks, draw their attention to instances of spiraling causality in their learning. You can also infuse examples into class dynamics. For instance, if you want the class to quiet down, ask in a soft voice just below the din, for everyone to get ready to listen. As it gets a bit quieter, ask them again in an even softer voice, and so on until they can hear you whisper!

Lesson 6
Learning About Mutual Causality

Understanding Goals

- Mutual Causality refers to a pattern in which two things impact one another (though not necessarily in the same way.)
- Causality is bi-directional in a mutual causal pattern.
- Mutual causality often refers to one event or process over time without an intervening feedback loop. Sequences of events between two entities with feedback are better described as cyclic causality.

Background Information

What is Mutual Causality?

Mutual Causality describes a pattern in which two things affect each other (though not necessarily in the same way). One event or process typically has an impact on both. The event or process might help both (mutually beneficial) or it might help one at the expense of another (a thief stealing, for example). When a bee takes nectar from a flower, the flower also is pollinated creating a mutually beneficial outcome.

The features of mutual causality include:

- Two events or processes impact each other so that each is a cause and each is an effect.
- The causal pattern goes in both directions (unlike dominoes)
- There is an effect in both directions, but that doesn't necessarily mean that the outcome is has the same type of impact in both directions, it could be good in both directions, bad in both directions, or good in one and bad in the other (as with parasites)
- Sometimes there are not two distinct effects but one outcome that is the result of the two causes (as in the attraction between electrons and protons).

What Experiences with Mutual Causality Might Students Have?

There are many examples of mutual causality in our everyday experiences. For instance, we often talk about "win-win situations" or intentionally look for mutually beneficial trades and exchanges. Even when we aren't explicitly looking for them, emotional instances that have mutually beneficial outcomes are emotionally reinforcing, increasing their likelihood.

There are also many examples in science as in symbiotic relationships where an action (such as a bee pollinating a flower) results in effects (albeit different) on both organisms (the bee gains pollen and the flower is fertilized). Symbiosis includes the forms of parasitism and mutualism. The one event, act, process, or relationship does not necessarily have positive effects in both directions. In the case of a tick sucking blood from a dog, the tick gets nourishment and dog is weakened.

Mutual causality is strongly characterized by simultaneity in terms of the mutual impact, where one event or process impacts each of the entities involved. However, it is not impossible for the mutually impact to play out over time. Once the interactions that fuel it become sequential in character with a feedback loop, they are better characterized by cyclic causality. The causal patterns share features which make them overlap to a certain extent even though they have features to distinguish them.

Lesson Plan

Materials

- White, unlined paper
- Board
- Video clips

Prep Step

- Review the lesson plan, background information, and understanding goals.
- Download videos before class or set up Internet access.

Step 1: Thinking About Current Conceptions

Ask the students if they have ever heard of a "win-win" situation. What does it mean? It actually can have two definitions. The first refers to a situation where a compromise or exchange is a win for both people involved. The second is a situation where either of two alternative outcomes is considered positive. We are focused on the first definition.

Invite the students to each find a place at the board and to list two to three examples of win-win situations.

Then invite them into a silent sharing where they go around and read everyone's ideas.

Step 2: Mutual Causality in Depth: Features and Variations

Ask the students to consider what type of causality is in play. How would they describe it? What features does it have?

Pass out paper and ask them to draw a diagram showing how the causality works. Then have them step back from the diagram and explain its features.

Mutual Causality has the following features:

- Two events or processes impact each other so that each is a cause and each is an effect.
- The causal pattern goes in both directions (unlike dominoes).
- There is an effect in both directions, but that doesn't necessarily mean that the outcome is has the same type of impact in both directions, it could be good in both directions, bad in both directions, or good in one and bad in the other (as with parasites).
- Sometimes there are not two distinct effects but one outcome that is the result of the two causes (as in the attraction between electrons and protons).

Make sure that you have discussed each of these features.

Step 3: Exploring Mutual Causality in Depth

Discuss the following three examples with the students. How would they describe the mutual causation in each case? If students seem unclear on the features of mutual causality, then you may wish to have them stop after each one to discuss it.

Example #1: A bird called the Egyptian Plover eats insects from the backs of rhinos, giraffes, and buffaloes and even eats leeches from the teeth of crocodiles. The plover keeps the animals which it tends clear of parasites and other bugs while having a steady food supply.[2]

Example #2: Aphids are small soft insects that drink sap from plants. They use a little pointed, straw-like structure to pierce the plant and suck out the plant juices. They process a lot of plant sap in order to get enough nutrients and amino acids and the excess gets excreted. It still contains a lot of plant sugar at this stage. Some species of ants use the excess sap. They find a colony of aphids and tend the colony and take the extra sap. They protect the aphids from predators and parasites and move the aphids around to new plants.[3]

Play the You-Tube Video by the BBC entitled, "Crazy Ant Farmers: Weird Nature." Available at: http://www.youtube.com/watch?v=43id_NRajDo&feature=fvw

Example #3: Play the You-Tube Video by the BBC entitled, "Animal Partnerships- David Attenborough- BBC Wildlife." Available at: http://www.youtube.com/watch?v=Qqa0OPbdvjw

These stories come from nature. Can they generate examples from across the curriculum? How about in history? Can they generate examples of mutual causality?

[2] Source for text on Egyptian Plovers: http://www.saburchill.com/ans02/chapters/chap011.html
[3] Source for text on aphids and ants: http://www.nearctica.com/ecology/pops/mutual.htm

Step 4: What Makes Mutual Causality Hard to Think About?

Mutual causality is easiest to notice when the impacts on both sides are obvious. However, this isn't always the case. Sometimes it is hard to notice impacts on one side of the case because one side of the equation might be less dramatic and/or take longer to notice (a tick benefits from being on a dog and while the dog is weakened, it is not typically noticeable) or might be viewed as passive (as in attraction between protons and electrons). Try to generate some examples of these with the students.

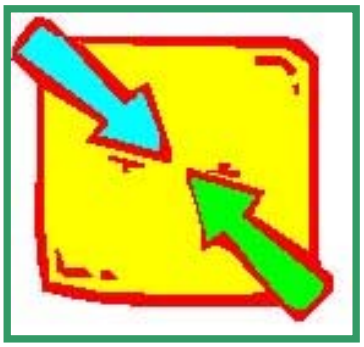
How is mutual causality similar to and different from cyclic causality? Some people see them as being quite similar because they each involve impacts on another entity, however, cyclic causality involves a feedback loop where one thing precipitates another thing happening and so on. It is more sequential in nature.

Step 5: Making Connections

In the coming weeks, draw their attention to instances of mutual causality in their learning. You can also infuse examples into class dynamics. Look for opportunities to help them engage in mutually beneficial exchanges!

What is Mutual Causality?

We are used to thinking about cause and effect as one-way: one thing makes another thing happen. But it is not always this simple. Sometimes one event, process, or relationship has two-way effects or bi-directional effects. For instance, when a bee pollinates a flower, the bee and the flower are both affected. The bee gets the nectar it needs for food energy and the flower gets pollen picked up by the bee from other flowers. This enables it to reproduce.



Sometimes the effects are beneficial for both things, such as in the example above. However, sometimes the effect on one is negative and the other is positive, such as when a tapeworm attaches to the intestines of a dog. The tapeworm benefits by getting the energy that it needs, but the dog loses energy to the worm and may be weakened.

How does Mutual Causality work?

- Two things impact one another (though not necessarily in the same way.)
- Causality is bi-directional in a mutual causal pattern.
- It refers to one event or process over time without an intervening feedback loop. Sequences of events between two entities with feedback are better described as cyclic causality.

Questions to Think About:

- How is Mutual Causality different from Domino Causality?
- What examples of Mutual Causality can you think of?

Lesson 7
Learning About Relational Causality

Understanding Goals

- Relational causality refers to instances where the outcome is caused by the relationship between two variables.
- Focusing on just one half of the equation often leads to incorrect predictions or limited ideas about what might influence an outcome.
- Relational causality plays a role in many everyday events.

Background Information

What is Relational Causality?

Relational Causality involves recognizing that outcomes can be caused by a relationship between two variables or entities. The relationship is typically one of balance or imbalance between the elements of a system. So in essence, neither element is the cause by itself. For instance, whether a scale balances or not depends upon what is in the other side. Your students are likely to have experience with seesaws and will know that whether they go up, down, or balance depends up who they are on the seesaw opposite. Similarly, whether they are younger or older depends upon who they are being compared to. Talking about relational causality and predicting outcomes always involves an implicit comparison.

The features of relational causality include:

- The relationship between two or more variables accounts for the effect.
- There is more than one variable in play.
- There may be a relationship of balance or equivalence or there may be a relationship of imbalance or difference.
- Shifts in the relationship can account for changes in the outcome.
- Changes in both variables that maintain the relationship between them do not cause differences in outcome.

What Experiences with Relational Causality Might Students Have?

There are many examples of relational causality across the curriculum and in life. In science class, differentials in air pressure enable us to take every breath, fish to regulate where they are in the water, submarines to rise and fall, planes to fly, and syringes to work. In ecosystems science, the relationship between different animal populations leads to balance or flux. In social studies, election results are structured by relational causality. It doesn't really matter how many votes you have as long as you have more than your opponent. Outperforming a warring faction underlies many historical outcomes. Outperforming the other team determines the outcome of many sports rivalries.

At the same time, relational causality can be hard to detect. Often the variables are non-obvious. You can't see air pressure for instance. Or we focus just on those relevant to us—what

our team is doing, how big we are when we get on a seesaw, what our own successes and failures might be. Attending to when a relational causality may be in play can help us to detect these variables and to take them into account.

Lesson Plan

Materials

- Journals, white, unlined paper, or small white boards
- Syringe
- Pan balance
- Glass jar with oil, dish soap layered in it (If possible have enough of each item available so that students can really study them.)

Prep Step

- Review the lesson plan, background information, and understanding goals.
- Gather the science materials.

Step 1: Starting with Students' Ideas

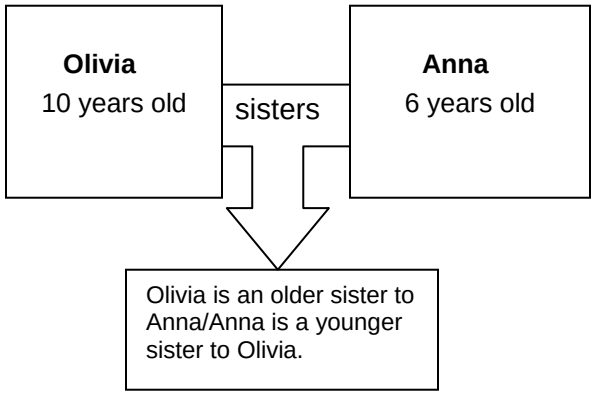
Show the students the syringe; pan balance; and glass jar with oil and dish soap layered in it. Explain that these things all look very different on the surface, but that there are deep similarities in how they work. Have the students work either alone or with a partner to draw models of how each of the three items works. Then have them team up with a few other students to discuss their ideas. At this point, they may realize some of the features that relate to relational causality, but possibly not. If not, pause and do the next part of the lesson and then come back to the examples. Explain that each of these items involves relational causality in how it works.

Step 2: Relational Causality in Depth: Features and Variations

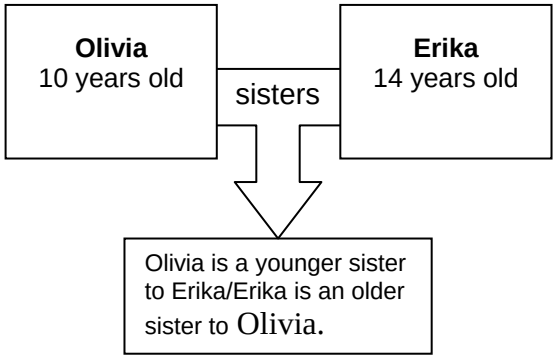
Explain to your students that they are going to look at a social example to help them think about Relational Causality. Say, "Two girls, Olivia and Anna, can be sisters, but neither girl alone is the 'cause' of being sisters. It is the relationship between the two that 'causes' them to be sisters."

"You *can* make comparisons about the relationship. For example, you can say that one sister is older and one is younger but it only makes sense in terms of the relationship, in comparison to each other. So you can see that it if one thing changes so does the outcome."

Draw the following diagram on the board:



Explain to your students that if you change one part of the relationship, the outcome changes. You can't change your age, of course, so we need to change one of the "things" entirely. Show this in the diagram.



Hand out and discuss the sheet, *What is Relational Causality?*

See if the students can come up with the features of relational causality. The features include:

- The relationship between two or more variables accounts for the effect.
- There is more than one variable in play.
- There may be a relationship of balance or equivalence or there may be a relationship of imbalance or difference.
- Shifts in the relationship can account for changes in the outcome.
- Changes in both variables that maintain the relationship between them do not cause differences in outcome.

Encourage the students to ask questions of clarification. Explain that they will work in groups again and try to explain each of the examples using relational causality.

Step 3: Mapping Relational Causality to the Examples

Have the students work together to try to explain how each example involves relational causality. Circulate while they are working offering assistance. Have them share their discoveries for each. Help them to realize the following:

1. The syringe depends upon air pressure. If you cover the end with your finger, you create air pressure differentials between the inside and the outside and reach a point where you cannot push or pull it.
2. Whether the balance evens out or not, depends upon how much mass is in each pan in relation to the other side.
3. The liquids in the bottle rise to the top or the bottom depending upon their density. If one of the liquids were substituted with a different one, what goes up and what goes down might change. They are only on the top or the bottom in relation to each other.

When talking about relational causality, it is important to use relational language. Using terms 'lower pressure' and 'higher pressure' accentuate the relationship by using 'lower pressure' and 'higher pressure' when discussing pressure differentials.

Step 4: What Makes Relational Causality Hard to Think About?

Ask what was easy or hard about analyzing the examples. Often relational causality is hard to detect when there are variables that it is hard to know about such as air pressure.

For reinforcement, you may want to show the You-Tube Video where a 55 gallon drum is imploded (55 Gallon Drum Crush available at: http://www.youtube.com/watch?v=Uy-SN5j1ogk) This is entirely due to air pressure differentials inside and outside of the drum. (Heating the drum causes the air to expand and some moves out of the drum. Quickly cooling the drum leads the air to contract but when air cannot take up the additional space, it lowers the air pressure in the drum relative to outside the drum and the outside air pressure pushes hard enough to implode the drum. There is a similar example (though smaller!) in the videos that they will watch in Lesson 8.

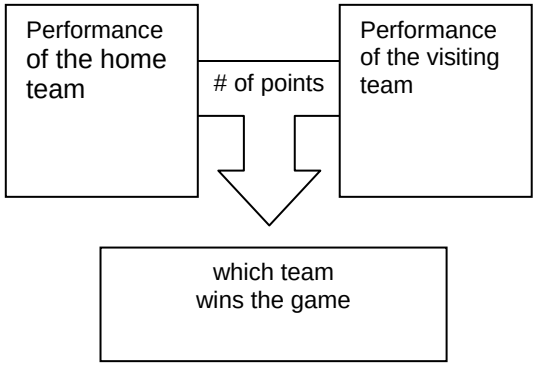
Step 5: Making Connections

Encourage the students to contribute to a list of examples of relational causality over the next few weeks. They should look for examples in the everyday world, science, social studies, sports, and beyond.

What is Relational Causality?

In Relational Causality…

1. …a relationship between two things causes something to happen. It is more than just having two things, there needs to be a relationship between them.



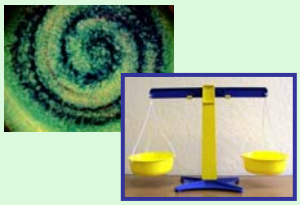
2.…the amounts of the two things are equal or different, and that tells you the outcome. (For instance, one is younger/older, more/less, higher/lower, etc.)

Ask yourself these questions:

- Must the two things work in <u>relationship to one another</u> to make the effect happen?
- If one of the two things changes (so that the relationship changes), does the outcome change?
- Can a comparison be made between the amounts of the things?

It is NOT Relational Causality if:

- One cause can result in the effect without the other cause.
- You have two causes, but there is no comparison between them, (for instance, you just add them up or do first one and then the other).



Lesson 8
Comparing Forms of Causality

Understanding Goals

- Spiraling causality (or escalating causality) is a form of cyclic causality, where in some instances, with each turn of the cycle, the level of the effects increases. In other instances, with each turn of the cycle, the level of the effects decreases.
- Mutual Causality refers to a pattern in which two things impact one another (though not necessarily in the same way.)
- Relational causality refers to instances where the outcome is caused by the relationship between two variables.

Background Information

Reinforcing the Causal Patterns

This lesson reinforces the three causal patterns considered in the previous three lessons. It aims to help students become familiar with the idea of multiple causal patterns and to help them realize that there are multiple patterns in the world. Discerning those patterns in everyday contexts and in contrast to each other deepens their understanding of the causal features of each. Some of the videos offer science examples (for instance, Albedo Effect or imploding can) to compare to the everyday examples. Analyzing video examples of causality in the real world also helps students to discern the causal patterns despite nuances in the real world contexts.

Look back at the suggestions from our collaborating teachers in the *Background Information* section to Lesson 4. Listen carefully to how your students talk about each pattern. Try to discern confusions in their thinking between the different patterns.

Lesson Plan

Materials

- Journals or white, unlined paper
- Chart paper or board
- Video clips of causality: clowns; Albedo Effect; cookie and milk sharing; bee and pollen; see saw; and imploding can downloadable from the *Causal Patterns in Science* website: http://www.cfa.harvard.edu/smg/Website/UCP/causal/causal_examples.html

Prep Step

- Review the lesson plan, background information, and understanding goals.

Step 1: Analyzing the Causality in Video clips

Remind the students about the causal patterns that they have learned. Explain that in this lesson, we will be again looking at some videotaped examples of things that happen and will talk about the patterns involved. Don't preface the patterns—let the students decide what they think each one is.

Show the first video clip of the clowns. Before discussing it as a class, ask the students to draw a diagram of what they think is happening. Then ask:

"How would you describe the causal pattern involved in what is going on in the video?" Ask the students to draw a diagram for the causal patterns that they found in each video.

Show each video clip and discuss it. Then contrast the videos and the diagrams as a whole. What was happening in each video clip? How were the videos similar? How were they different? Gather ideas. After going through each example in this way, then compare the three types of causality involved.

Step 2: Contrasting the Key Features of the Causal Patterns

Have students compare the features of their diagrams and the video examples. How were they similar? How were they different? Hopefully the students will have noticed the following features in their discussions above. Be sure to discuss these features explicitly.

Spiraling

- One thing impacts another which in turn impacts the first thing (or alternatively impacts something else which then impacts something else and so on, but eventually impacts the first thing) with amplification or de-amplification of effects
- Involves feedback loops
- It is sequential as each event is a reaction to the one before it
- Often a clear beginning and ending

Mutual

- Two events impact each other so that each is a cause and each is an effect.
- The causal pattern goes in both directions (unlike dominoes)
- There is an effect in both directions, but that doesn't necessarily mean that the outcome is has the same type of impact in both directions, it could be good in both directions , bad in both directions, or good in one and bad in the other (as with parasites)
- Sometimes there are not two distinct effects but one outcome that is the result of the two cause (as in the attraction between electrons and protons).

Relational

- A relationship leads to an outcome
- one thing makes another thing happen
- simple, short
- cause leads directly to an effect

Ask students what they found difficult about this. Gather ideas.

Here are some sample comments about each clip:

Video #1: Clowns
“Escalating causality! It is cyclic as one does some thing and the other responds, but it certainly escalates with each turn of the circle.”
“Right, it’s hard to guess where it will go at the outset, but escalation is like that.”

Video #2: Albedo Effect:
“It is cyclic causality but it could increase each time. The less ice there is, the more the earth absorbs the heat from the sun and the more the ice melts. It just keeps escalating.”

Video #3: Imploding Can
“The can crushes because of the greater air pressure on the outside than the inside of the can—that makes it a relational causality.”
“You have to have some science knowledge to understand this one. The evaporating water leads to less air pressure inside that outside of the can.”

Video #4: See Saw
“If it goes up and down depends upon what is on each side. It is a relationship.”
“It is like a comparison that makes what happens happen.”
“You have to have two things and whether they are different or the same—in terms of weight here—makes the outcome what it is.”

Video #5: Milk and Cookies
“He gave her milk and she gave him cookies—they affect each other.”
“It’s a two-way causality—like a win-win for both of them.”
“It is a mutual impact.”

Video #6: Bee and Pollen
“The bee gathers nectar and pollen and the flower gets pollinated—it is mutual.”
“Symbiosis, as shown here, involves a mutual relationship.”

Step 3: Making Further Connections

In the coming weeks, ask students to keep a log of the different causal patterns that they can detect. Have them list all six in their journals and to try to find at least five examples of each type. Encourage them to look across the curriculum and their everyday lives so that they have a diverse set of examples.

Notes for Teachers: Features that Make Causality Complex

As discussed in the introduction, there are various features the make understanding causality especially complex. These can make it harder to see the causal patterns. However, teaching the causal patterns can also help you to address these features because they invite students to probe further and to see if the pattern that they are investigating is more complex than they first realized. For instance, considering whether something is relational or not, may lead you to notice non-obvious causes. But it goes both ways. Asking whether there are non-obvious causes in play, might lead to recognizing a relational causal pattern. This section considers some of the most prominent complexifying features.

Non-obvious Causes

It makes a lot of sense to begin an investigation looking for obvious causes. But often, causes are not obvious: air pressure, germs, microbes, attraction between electrons and protons, and so on. Talking with students about the unseen world and helping to direct their attention to these possible causes will help students bring them into their realm of possibilities. Some causes are inferred and those may be harder to talk about. Inviting students into the microscopic world with a microscope, computer, and projector is one way to help them enter these possibilities.

Time Delays Between Cause and Effect

Time delays between cause and effect make it harder for us to realize that there is a relationship between the cause and effect. Time delays can be complicated in many ways. We can slowly add carbon dioxide into our atmosphere resulting in climate change. But even if we reverse our actions, we will not see an immediate effect (or even nearly immediate effect) of doing so. This can lead us to the wrong conclusions about whether or not something matters. It makes it very hard to detect the forms of causality in play. (It also can be de-motivating.) In the course of the everyday curriculum, helping students to unpack examples where the delay between causes and effects complicates interpretation (seeing the stars; getting sick in terms of the time from infection to symptoms) may help them to reason about evidence in more complex ways.

Spatial Gaps Between Cause and Effect

We often do not know how to draw the parameters of problem spaces and often they extend far beyond what we realize. As ecosystems scientists know, the parameters of water sheds are far beyond what people realize. We struggle with understanding how our actions can impact polar bears who seem a world away to us and how we could be responsible for what happens in

underdeveloped nations due to the impacts of climate change. Conversations in the classroom can help students think about where they construct these boundaries.

Multiple Causes

We often stop after we find a cause for something, yet often there are multiple sufficient causes that can result in an outcome. For instance, there's more than one way to pollute the air or a water source. If we don't realize that multiple causes are in play it is harder to detect possible interactions between them and we may emerge with only a tiny bit of the causal story.

Decentralized Control

Along with looking for single causes, we often look for centralized ones. Increasingly, students have experiences with emergent effects as they use the Internet, witness the construction of Wikipedia, etc. There are many opportunities in a classroom to talk about decentralized versus centralized causality—structures of both types exist in schools. Comparing and contrasting them and generating examples can expand students' causal reasoning.

Reinforcement Activities

These resources offer an opportunity for students to think creatively about the causal patterns and to further develop their understanding.

Skits to Demonstrate Different Causal Patterns

Social Examples can be a great way into thinking about causality. One way to do this is to tell little stories (a rumor getting started, a conflict that escalates, etc.) These can be a great warm-up to creating skits that demonstrate different causal patterns. Have students generate a couple of ideas in small groups and then choose the best one and plan it out. It can be hard to depict some ideas in a skit so they'll need to think about what they are able to show. Remind the students that some of the video examples were social examples.

Have the students act it out and have their classmates guess what pattern they are enacting.

Ask, "What features does each skit show well? What features should the skit show for that pattern of causality? What improvements would you make?"

A variation on this activity is to take one situation and then have it end in a couple of different ways—perhaps showing more than one type of causal pattern. (For instance, what if you took an escalating pattern and stopped it? Of if you went from a branching pattern to a cyclic one?)

Sayings In Everyday Life

Often we use sayings in everyday life that relate to different types of causality. Analyze the ones here and then see what others your students can add.

"What goes around comes around."
"Every vote counts."
"Pay it forward"
"The whole is greater than the sum of its parts."

Stories to Explore Causal Patterns

Teachers with whom we have worked over the past 15 years have suggested stories to us that can be useful in teaching causal patterns. The list of stories below was compiled by Amy Hart Hammersle to be used by teachers of all ages. For younger children, the stories will hold a lot of interest, but older students may also enjoy hearing them and analyzing the inherent causal patterns.

If you want to pursue this further, a graduate student who worked with the author and the Understanding of Consequence Project in its early days, Linda Booth Sweeney, wrote a book

about using stories to teach systems concepts called, “When a Butterfly Sneezes.” It is written more from a systems thinking perspective than a strict causality perspective, but it may be useful.

DOMINO CAUSALITY

Lights Out *by Arthur Geisert*
A young pig is afraid to fall asleep with the light off, which poses a problem when his parents insist that the light go off at eight. To solve his dilemma, the piglet crafts an elaborate twenty-nine step Rube Goldberg contraption that buys him enough time to fall asleep before the light shuts off. Domino causality is illustrated in the multi-step, chain-reaction mechanism the piglet designs.

If You Give a Mouse a Cookie *(and others) by Laura Joffe Numeroff*
A young boy starts a chain reaction after offering a visiting mouse a cookie. One request leads to another and another (He can’t have a cookie without milk, right? And of course he’ll need a straw to drink the milk…) until the boy is exhausted and the mouse circles back to his original request – a cookie. Also cyclic in nature, the domino causality in Numeroff’s book is both engaging and comical. Other books in the series (If You Give a Moose a Muffin, If You Give a Pig a Pancake) illustrate domino (multiple linear) causality. Domino causality is explicitly illustrated in the chain reaction that leads the mouse to ask for successive related items from the boy (domino) until he returns to his original request (cyclic).

The Lorax *by Dr. Seuss*
The Once-ler, seduced by the wonder of the Truffula Trees, begins clearing the forest in his quest to mass-produce the ever-versatile Thneeds. As he chops down Truffula Trees, however, he displaces the animals that rely on these trees for shelter and food. Eventually all the Truffula Trees have been cut and every animal has left, driven away by the chain reaction started by the Once-ler and his Thneeds. Domino causality is illustrated in the chain of events caused by the Thneed plant that ultimately displaces the other animals.

The King’s Stilts *by Dr. Seuss*
The Nizzards threaten to flood the Kingdom of Binn by eating away the protective roots of the Dike Trees that keep out the sea. King Birtram of Binn works hard to protect his Kingdom from the Nizzards by leading the fearless Patrol Cats, but he also likes to play hard. When Lord Droon hides the King’s stilts, his only toy, the King falls into a deep depression; the Patrol Cats likewise fall into disrepair, the Nizzards become bolder, and the Dike Tree’s roots threaten to give way to the sea. Only when the brave page boy, Eric, returns the King’s stilts is the kingdom saved. Domino causality is clearly illustrated in the chain reaction started by the theft of the stilts that ultimately endangers the safety of the city’s walls.

CYCLIC/SPIRALING CAUSALITY

Koi and the Kola Nuts *(Verna Aardema)*
Along his journey to win the hand of the great Chief’s daughter, Koi stops to help several animals in need with his bag of kola nuts. When Koi in turn is struggling, his new friends repay him for his kindness by helping him through his trials. Cyclic causality is illustrated in the reciprocal kindness of Koi’s friends, which in turn becomes the central lesson to this African folk tale.

The Dandelion Seed *by Joseph Anthony*
A young dandelion seed is reluctant to let go and fly the way other seeds have because he is scared of what he doesn't know about the world. When he finally lets go of his fears, the seed discovers that the world is actually exciting and beautiful. After settling miles away and growing into a new dandelion plant, he convinces another scared seed to fly away in a cyclic pattern of growth and development. Cyclic causality is illustrated in the pattern of fear, discovery, and finally sharing one's experiences with another experiencing the same fear.

The Very Hungry Caterpillar *by Eric Carle*
This beautifully illustrated picture book chronicles the growth of a very hungry caterpillar who eats, grows, becomes hungry again, eats some more, and continues to grow in a cycle fed by his quest for food. Cyclic causality is evident in the caterpillar's pattern of eating – burning energy by growing – getting hungry – eating again.

The 500 Hats of Bartholomew Cubbins *by Dr. Seuss*
Bartholomew Cubbins is a poor farm boy whose prize possession is the hat that was once his father's and his grandfather's before him. One day Bartholomew encounters the royal carriage but raises the King's ire when he fails to remove his hat. Discovering that each time he removes his hat another quickly takes its place, Bartholomew is dismayed – particularly when the King has him arrested for disrespecting royalty. Right as Bartholomew is about to be pushed to his death from the castle tower, he and the King realize that Bartholomew's five-hundredth hat has become the finest in the land. As he removes this last hat the spell is broken, and Bartholomew returns to his family after gifting this final headpiece to the king. This cyclic pattern escalates at the end of the story as each of the last fifty hats appears prettier and finer than the last until the grandest appears to save Bartholomew from his dire fate. Cyclic causality is illustrated when removing one hat causes the appearance of another; escalating causality is evident in the increasingly beautiful hats emerging each time Bartholomew doffs his cap at the end.

Grandpa's Soup *by Elko Kadono*
Grandpa mourns the loss of his wife, and to keep her memory alive he begins to cook the meatball soup she was famous for. He begins by making just enough for himself in the smallest pot in his kitchen, but the aroma draws three tiny mice to share his meal. The next day Grandpa makes a slightly larger pot and remembers a few more ingredients to the soup, and the aroma draws an even bigger (escalating) crowd of hungry visitors. Each day the pot gets bigger, the crowd grows, and Grandpa remembers a few more ingredients for the soup until he no longer feels lonely and sad. Cyclic causality is evident when each new batch of soup prompts grandpa to remember a new ingredient, leading him to make yet another batch.

The Butter Battle Book *by Dr. Seuss*
The Zooks and the Yooks fight over whether bread should be eaten butter-side up or butter-side down. The battle escalates as the Zooks fight back, and the weapons grow progressively larger with each new confrontation. Escalating or spiraling causality is illustrated when each new confrontation leads each side to return with larger, more dangerous weapons.

The Sneetches *by Dr. Seuss*
Mr. Sylvester McMonkey McBean offers the Sneetches without stars on their bellies the chance to become Sneetches with stars; the Sneetches with stars are appalled and fight back, removing their stars and embarking on a cyclic battle of 'stars on bellies.' Cyclic causality is

illustrated when one side's act causes the other to respond with an opposing act, starting a never-ending cycle of stars-off and stars-on.

The Gingham Dog and the Calico Cat *by Eugene Field*
The longer the gingham dog and the calico cat fight, the more they are torn apart until nothing is left but scraps of calico and gingham. Escalating causality is illustrated in the increasingly destructive battle that results in the ultimate destruction of both main characters.

RELATIONAL CAUSALITY

The Water Hole *by Graeme Base*

In a touching illustration of the tragedy of the commons, the animals discover that their beloved water hole is shrinking as more and more animals drink from it. Fueled by the lack of rain, the diminished water supply eventually forces the animals to find other sources to quench their thirst. Relational causality is evident in the relationship between the number of animals using the water supply and how much is available.

Benjamin's Balloon *by Alan Baker*
Benjamin the mouse is lifted up, up, and away after inflating his purple balloon too much. As the air escapes, Benjamin plummets back to earth in this elemental example of relational causality. Cyclic causality is also illustrated when Benjamin, covered in snow, rolls down the hill, gathering speed, more snow, and yet more speed as he races to the bottom.

Boo and Baa Have Company *by Lena and Olof Landström*
Boo is stranded in an upper tree branch after attempting to save a stranded kitten. Baa's attempt to save him by lowering him down via a rope tossed over the branch has disastrous results when she discovers that Boo's many sandwiches have made him too heavy for her to hold. Relational causality is illustrated in the weight differential between Boo and Baa that upsets her rescue attempt.