Note! This was originally Lesson 3 (out of 8 lessons) in the NESSP ROADS from Earth to Venus Student Challenge and Companion Course.

Learn more about NESSP here.

Modeling Moving Carbon

Lesson Level Question: *What is carbon and how does it move and change on Earth and Venus?*

Lesson Summary: *Students will begin by putting a series of cards in order to tell a story about how carbon moves and changes in a tree, and then engage with two rounds of a carbon cycle game. Next, students will assemble a fructose molecule model as part of a photosynthesis activity. After reflecting on and connecting the card set, the carbon cycle game, and the fructose model, students will be prepared to create a local carbon cycle model. Finally, they will research conditions on Venus to create a version of the carbon cycle game for that planet. To close the lesson, students will document their activities and learning*

Standards Links: *Click here for information about NGSS standards alignment.*

Materials Provided by the Teacher	**5 E Lesson Summary**
Bingo Chips and baggies for fructose model Printed cards for carbon story card sort (Engage) - (or use the electronic version) Printed cards and handouts for carbon cycle game (Explore) (or use the electronic version) Printed cards for fructose model (Explore) (or use the electronic version)	**ENGAGE:** Students will organize a card set to tell a carbon-related story. **EXPLORE:** Students will engage in two models of carbon moving and changing, one at the macro level and one at the micro level. **EXPLAIN:** Students will relate both of the carbon models from “Explore” to create a model of the carbon cycle in their local area (or create a local carbon story-telling card set). **ELABORATE:** Students will conduct research about Venus in order to create a Venus version of the carbon cycle game. **EVALUATE:** Students will document their work and learning for this lesson. **EXTEND**: Students will investigate NASA careers related to the work of this lesson.

Before The Lesson

- **Engage**: If you want your students to engage with the card sort in pairs or small groups, print and cut enough card sets for your class.
- **Explore**: Review the teacher notes and preparation tips for the carbon cycle game and the fructose model. Both require decisions on your part, as well as preparations and materials. Support videos for each model are also available (linked in sidebar of Explore.)
- **Explain**: If your students are in Grades 3-5, decide if they will create a new carbon story card set OR a local carbon cycle model
- **Elaborate**: Preview the online Venus resources and decide which ones you will give to students for their research.
- **Evaluate**: Read the deliverables list in the “Evaluate” portion of the teacher guide so that you know where this lesson is going.

Lesson Plan

<table>
<tr><th>Phase</th><th>Middle School</th><th>Materials/Prep</th></tr>
<tr>
<td>Engage
(30 Min)</td>
<td>
Students will organize a card set to tell a carbon-related story.
First, decide how you will engage students in the card sort. You have several options. Resources for these options are all in the Google Slides linked in the sidebar. In all cases, have students work with a partner or small group. They should put the seven cards in an order that makes sense to tell a story and be able to explain why they chose that order.
<table>
<tr>
<td>If you plan to engage students electronically as a whole class:
Display Slide 2.
Be sure not to display Slides 3 or 4.</td>
<td>If you plan to engage students electronically in pairs or small groups:
Make a copy of the slides file so that you can make edits.
Duplicate slide 2 for each pair or group. Make sure that each pair or group knows which slide is theirs.
Be sure to delete Slides 1, 3, and 4.
Give students edit access to the Google Slide file.</td>
<td>If you plan to engage student pairs or groups with a printed card sets:
Print enough copies of Slide 3 so that each pair or group gets a full set of 7 cards (4 groups per page).
Cut the card sets apart and give each pair or group a full set of 7 cards</td>
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<td>Circulate as students work. Listen in on their conversations to understand how they are thinking about the task. The main purpose is for you to understand their thinking and prior knowledge about carbon and the carbon cycle.</td>
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<td>Engage Card Sort:
Google Doc
Power Point
PDF</td>
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Grade Level Adaptation

The depth and format of explanation that you ask your students provide will be based on their grade level and prior knowledge of the carbon cycle. If your students can readily provide the level of explanation described for their grade level below, consider asking them for additional explanations for higher grade levels:

Grades 3-5 / Little or No Prior Carbon Cycle Experience

- Verbally explain why they put the cards in the order that they did, using words like “First, next, then.”
- Provide common sense explanations such as “the small tree grows bigger” for their order.
- After providing their sort order and explanation, pairs, groups, or the whole class should ponder and discuss questions such as these, with no expectation of a scientifically correct answer yet:
    - How is the tree getting bigger over time?
    - Where did the firewood “go” after it was burned?

Middle School / Some Prior Carbon Cycle Experience

- Students should be able to explain their card order verbally or in writing.
- If students have prior knowledge of the carbon cycle, you may wish to consider giving students a word bank **after they have finished their ordering** to help increase the academic vocabulary. The purpose of the word bank is to help support their explanations, not to provide definitions with these words. If students have no prior experience with this vocabulary, do not provide this word bank. Words could include:
    - Atmosphere, carbon, carbon dioxide, photosynthesis, combustion, mass, sunlight, energy.
- After providing their sort order and explanation, pairs, groups, or the whole class should ponder and discuss questions such as these, with no expectation of a scientifically correct answer yet:
    - Consider the mass of the tree. How is it changing? Where is it coming from, where is it going from card to card?
    - What questions do you have about how and why this all happens?

High School / Prior Experience with the Carbon Cycle

- Students should be able to explain their card order verbally and in writing, using some academic vocabulary such as:
    - Atmosphere, carbon, carbon dioxide, photosynthesis, combustion, mass, sunlight, energy, reaction, respiration, cellular respiration.
- If students have prior knowledge of the carbon cycle, you may wish to consider giving students a word bank **after they have finished their ordering** to help increase the academic rigor of their explanations. The purpose of the word bank is to help support their explanations, not to provide definitions with these words. If students have no prior experience with this vocabulary, do not provide this word bank.
- After providing their sort order and explanation, pairs, groups, or the whole class should ponder and discuss questions such as these, with no expectation of a scientifically correct answer yet:
    - Consider the mass of the tree. How is it changing? Where is it coming from, where is it going from card

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to card?
- Where is the carbon in each card, and how is it moving or changing between each card?
- What is causing the carbon to move or change between each card?
- What do you clearly understand and what is still confusing or mysterious about why this all happens?

After students have discussed in pairs or groups, consider a whole-class discussion using the prompts and questions above. Again, the purpose of this is not for students to arrive at complete, scientifically accurate explanations. Rather, it is for you to understand their early thinking and prior knowledge around these topics. Another prompt that should be used regardless of students age level or prior experience is:

- What personal connections can you make with this card sort? Have you ever found a pine cone, planted a tree or other plant and watched it grow, or had a campfire?

Say: “Next, we are going to play a game about the carbon cycle. As we play, keep this card sort in mind to see if you can find any connections between the card sort and the game.”

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Explore (135 min total)

Part 1 (60 Min)

Part 2 (30 min)

Part 3 (45 min)

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Students will engage in two models of carbon moving and changing, one at the macro level and one at the micro level.

This “Explore” section has three parts:

- **Part 1: Play the Carbon Cycle Game (original Fossil Fuels station card).**
- **Part 2: Play the Carbon Cycle Game (new Fossil Fuels station card).**
- **Part 3: Fructose Photosynthesis Model**

These models are complex and require some set-up, so please ensure that you’ve reviewed the teacher preparation notes ahead of time!

Part 1: Carbon Cycle Game Round 1

Thoroughly review the Carbon Cycle Game directions (linked in sidebar), decide the style of game play you will use (whole class kinesthetic model or online slides version) and prepare the materials and print-outs accordingly. The instructions are linked in the side bar.

Before you begin, make sure that each student has a copy of the “Part 1” student handout (linked in the sidebar as part of the Carbon Cycle Activity) and go over how the game works and what they should be recording. You may wish to model 1 or two rolls to ensure that students understand the process before starting to record themselves. You may also need to ensure that students know that each of their handouts will be unique--they will not all be recording the same “path” as they roll.

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Teacher-facing support videos for these models:
Carbon cycle video:
Lesson 3: Carb…
Fructose Model video:
Lesson 3: Fruct…

NOTE! These videos are NOT for students.

Parts 1 and 2:

Carbon Cycle Game Instructions

Carbon Cycle Station Cards

Carbon Cycle Game:
Round 1 (Google Slides)
Round 2 (Google

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Grade Level Adaptation

Younger students or those with little or no prior experience with the carbon cycle may need support before they begin to understand some of the vocabulary on the station cards.

For example, “sedimentary rock” might be an unfamiliar word to some. In this case, resist providing a formal definition to all students. Instead, direct student attention to that station card. Ask them to consider the title and image and what they think it means. Only provide student-friendly definitions if no one in the class volunteers ideas like these.

- CO2 or Carbon Dioxide - it’s a gas, it has to do with breathing and plants
- Fossil fuel - coal or oil
- Sedimentary rock - rock formed in layers over time
- Atmosphere - all the air around us
- Photosynthesis - how plants grow and make food
- Reservoir - places in the carbon cycle where carbon is
- Process - why carbon moves or changes, there are lots of different processes

Assign students a “start” station”, with at least one student starting at each station. All students will start at a station and list it as “Start at” in Row 1. They will roll their dice and see what the Station Card directs them to do and write their new station under “Move to” in Row 1. They should also read the explanation on the station card that explains WHY they are making this move. This new station then gets entered as the “Start at” station in Row 2. They should continue this until they have filled out all 10 rows. In the final column of the handout, what students record will vary based on grade level and prior knowledge. They might put unfamiliar vocabulary words from the station card or explanation of movement (beginners) or name the process that is causing them to move such as respiration (advanced).

After all students have finished 10 moves, it is time for small group discussion. If students are already in groups, they can stay in those groups to discuss or form new groups. If students are not already in groups, form groups of 4.

First, ask students to compare the “path” that each member of their group took as they move through the carbon cycle. Ask them to consider:

- Did you all start at the same station? Did you all follow the same path? Did anyone visit all of the stations? Who visited the fewest stations?
- This game is about the carbon cycle. What does the word “cycle” mean to you? Did you move in a “cycle” in this game?
- What represents the carbon (or carbon atoms) in this game? (Answer: the students themselves were the carbon atoms.)
- What connections can you make between the card sort we did and the game we just played? What stations are represented in the card sort? How is carbon moving or changing? What improvements can you make to your initial explanation of the card sort?
- Compare the game we just played to this common way that the carbon cycle is often shown (Display on the projector). How are they similar? How are they different?

Slides)

Round 1 (PowerPoint)
Round 2 (PowerPoint)

Round 1 (pdf)
Round 2 (pdf)

Student Pages (Round 1 and Round 2)
Google Doc
Word Doc
PDF

Carbon cycle diagram
https://www.usgs.gov/media/images/usgs-carbon-cycle

Part 3

Fructose Model - Teacher Directions

Fructose (Sugar) Molecule Student cards
(1 per pair or group)
Google Doc
Word Doc
PDF

bingo chips (3 colors)
baggies for bingo chips
flashlights

Circulate as students discuss. Bring the class back together as a group and call on a few students who had good insights into the questions above, based on your circulating among them as they spoke. If a student had a particularly “interesting” or strange path in the game (for example, if someone never left a single station or visited all of the stations), you may wish to share those with the whole class.

You may wish to use different reflection questions based on the grade level/prior experience of your students. Here are some selections to augment the basic reflection shown above. You may choose to ask one or more of these questions in addition to hte basic reflection shown above.

Grades 3-5 / Little or No Prior Carbon Cycle Experience

1. **Movement or Stays Still** Sometimes you moved to a new station, sometimes you stayed put. Why do you think carbon might stay in one place for a long time in nature?
2. **Cause & Effect** What might make carbon move from one place to another, like going from the atmosphere into plants?

Middle School / Some Prior Carbon Cycle Experience

1. **Time Scales & Rates** Which movements do you think happen quickly in nature (days to years), and which ones happen very slowly (thousands or millions of years)? How does our game show that?
2. **Model Strengths & Limitations** What parts of the carbon cycle does our game model well? What parts might it oversimplify or leave out?

High School / Prior Experience with the Carbon Cycle

1. **Analyzing Your Data** *Check for understanding:* Review your path of travel across 10 rounds. Can you summarize how often you ended up in fast-cycling reservoirs (like atmosphere, surface ocean, biosphere) versus slow-cycling reservoirs (like rocks and fossil fuels)?
2. **Model Simplification vs. Complexity** All models simplify reality. Where does our game simplify important details of the carbon cycle (e.g., chemical forms of carbon, microbial processes, ocean layers, volcanic processes, etc.)?
3. **Carbon Reservoir Capacity** In reality, sedimentary rocks hold the most carbon. How might our game illustrate the huge imbalance in reservoir sizes, and why is that significant for climate stability over geologic time?
4. **Human Influence & Mitigation** If we added processes like burning fossil fuels for energy or reforestation, how would the dice rolls or station rules shift to show human impacts and possible climate mitigation strategies?
5. **Long-Term vs. Short-Term Changes** *More challenging:* Explain how short-term (years to decades) carbon movements differ from long-term (millions of years) geological cycles, and why it’s critical for policymakers and scientists to understand both scales.
6. **Evaluating Model Accuracy** What evidence or data would you collect to check whether a model like this accurately represents carbon movement in the real Earth system? How would you revise it based on your findings?

Fructose Model (Online version):
[Google Slides]
[PowerPoint]
[PDF]

Comparing and Contrasting Models Student Handout
[Google Doc]
[Word Doc]
[PDF]

Part 2: Carbon Cycle Game Round 2

Before starting the round, display both versions of the two Fossil Fuel station cards. Ask students to examine them and then discuss with a partner:

- What do they notice?
- What do they wonder?
- How do they think the game will change by swapping out the Round 1 version for the Round 2 version?

Allow students to discuss with a partner or small group before taking a few ideas from the class.

Make sure students have a Round 2 Handout. Play the game again, just like before, but with the Round 2 Fossil Fuel card. As students play the game, ask them to pay attention to whether or not this change impacts them, and what that impact might be. Older students and those with more prior experiences with the carbon cycle may be asked to be alert to ways that human activities might be changing the carbon cycle in other stations, and how we might change the game to reflect these human impacts. They can record these ideas in the last column of their handout.

Reflection: Ask students to discuss in pairs or small groups before discussing as a class.

- How did the second round of the game compare to their predictions?
- What other ways might humans impact the carbon cycle? Which station card would we need to change to reflect these impacts, and what changes would we make? If students have a hard time coming up with an example, suggest deforestation (cutting down a lot of trees) or reforestation (planting more trees) as an example. The initial card sort from "Engage" might be useful as a connection here!

Say: We have now told a story about carbon using the card sort, and we've seen a model of the carbon cycle in the game. This game is of the WHOLE carbon cycle and describes how carbon moves and changes in the entire system. Next, we will zoom into one small part of the carbon cycle that involves plants.

Part 3: Fructose Photosynthesis Model

Decide if you will do this activity as a whole-group demonstration (recommended for younger students) or as a small group activity (recommended for older students). Quantities are listed below for **ONE molecule**. We recommend 2-3 students work together on one molecule. So, prepare enough sets for each group to have their own molecule.

- Prepare 12 molecules in baggies
  - Make 6 H_2O molecules by placing two H (white/clear) bingo chips and one O (red) bingo chip into a baggie.
  - Make 6 CO_2 molecules by placing one C (black/grey) bingo chip and two O (red) bingo chips into a baggie.
- Print 1 fructose card (linked in sidebar)

Say: “Next we are going to model how plants use water and carbon dioxide to make food. Most plants make sugars. We are going to model how plants make fructose, which is a common type of plant sugar.”

First, it is important to make sure students can establish whether “H two O” means two hydrogen and one oxygen or one hydrogen and two oxygen. This is a common difficulty. This can be done by showing one example of each molecule (H_2O and CO_2) and asking “which one is water (H_2O) and which one is carbon dioxide (CO_2), and how do you know?” Circulate and listen as students discuss--in this case there IS one right answer!

- Evidence and Reasoning: “O” is the only one in common between the two molecules, so the color that appears in both bags must be “O”. CO_2 ends in a 2, so that must mean there are 2O and 1C in CO_2. The other one has 2H and 1O.

Whole-Group Demonstration

For younger students, it is a good idea to “construct” a fructose molecule as a class.

- Distribute the 12 “molecules” that you made out to students, and have one student hold the flashlight next to you.
- Put a printed out Fructose card on the table.
- Ask pairs of students (one with a water molecule and one with a carbon dioxide molecule) to bring up their molecules.
- Ask the student with the flashlight to turn on the light to break the bonds (students with molecules open the baggie), and make new bonds (students with molecules place the correct atoms (bingo chips) in the labeled spots of the fructose card.
- Continue to bring up more pairs of students to fill the fructose card.

What they will notice after a few rounds is that there is “no place” for the extra oxygen atoms. What happens to the extra (waste) oxygen? It is released into the atmosphere. You can place these around the card, but off the edge. Don’t worry about the idea that all oxygen atoms “pair up” as this is not as critical for younger students.

Small-Group Modeling

Make sure that each pair or small group has a fructose card and the 12 molecules they need. Ask them to predict what they will do next. Ask them what role the flashlight plays. (Alternatively--you can control classroom lights and have students proceed with breaking/making bonds when you turn the lights on.)

You may wish to demonstrate the first pair of molecules as described in the whole-group instructions above, or just release your students to build a fructose molecule.

Ask students what is “left over” and what they think happens to these atoms.

After building a carbon molecule, ask students how the carbon moved and changed. Ask them how this connects to both the card sort and the carbon cycle game. Where is this process happening in both the card set (between cards 2 and 3) and the carbon cycle game (when carbon moves from atmosphere to Plants on Land (and from Surface Ocean to Ocean Plants, although this is probably less obvious to students!).

Distribute copies of the “Comparing and Contrasting Models” Handout (linked in sidebar).

The goal is for students to fluently describe how the card sort, carbon cycle game, and fructose model relate. They are all trying to convey ideas about the carbon cycle. The card sort tells one story about how carbon moves and changes using pictures. The carbon cycle game is trying to show the whole enormous carbon cycle, and the fructose model is trying to show one tiny process in the whole system (photosynthesis). The card sort is a visual representation of several processes in the carbon cycle. All of these can be described as different ways to model how carbon moves and changes.

Teacher guidance:

Card Sort (Answer Key)	**Connection to the Carbon Cycle Game (Macro scale)**	**Connection to the Fructose Model (Micro scale)**
 Possible “titles” of this carbon story: From Seed to Ashes: A Story about a Campfire How a Pinecone Becomes a Fire	In the first three cards, the tree is shown growing. It is getting larger because of photosynthesis, especially from card 2 to card 3, which takes carbon from the atmosphere (station card) and into the tree (Land Plants station card). A very small amount of carbon may also enter through nutrients from the soil (station card), but most of the carbon comes from the atmosphere. Then, the tree is cut down. Carbon is stored in the tree trunk and firewood. When the tree is burned, where does the carbon go? A small amount remains in the ash and probably becomes part of the soil. But most of the carbon goes back to the atmosphere where it came from. We don’t have “burning” as an option on the “land plants” card, but should we? What would we change about the “Land Plants” card to account for this?	Photosynthesis allows plants to take carbon from the atmosphere while they are alive. So, the first three cards show this. It is how tiny seeds become large trees. After the tree is cut down, there is no more photosynthesis. The carbon is stored in the trunk of the tree. The opposite of the photosynthesis reaction is the combustion reaction. (Note! This is why we call it “burning calories” when we eat foods like sugar and get energy from it.) In the case of the tree, the carbon is released as gas when the tree is burned. The energy comes out as fire.

Explain (120 Min)

Students will relate both of the carbon models from “Explore” to create a model of the carbon cycle in their local area (or create a local carbon story-telling card set).

[Explain (Local Carbon Cycle Examples)]

IMPORTANT TEACHER NOTE! The word "model" does not mean a 3D physical model. A model is any representation that can help us understand a complex system or idea. This representation might be an annotated map, a flow chart, an infographic, or any other labeled visual representation. Slides 2-5 of the attached "L3 Explain" slide deck (linked in sidebar) show several examples of place-based carbon cycles in different formats. It is up to you to decide when to share these examples with students at the start of this segment, share them later if students get stuck, or not share them at all.

In this section, students will apply what they have learned about carbon and the carbon cycle to create a local carbon cycle model. A grade level adaptation option for Grades 3-5 is shown first. If you teach middle or high school students, skip down to that part of the lesson.

Grades 3-5

Instead of the Place-based carbon cycle, teams in Grades 3-5 have an option to create a Place-based Carbon Story Card Set. This card set should:

- Have a short title that reflects the overall story that involves a local part of the carbon cycle.
- Include 6-10 cards in a sequence that show carbon moving and changing
- The carbon should move to a new reservoir at least twice and change form (solid, gas, liquid) at least once
- Include a written or audio recorded description of what is happening in the card set.

This card set should be modeled after the card set and description introduced in "Engage of this lesson and discussed again at the end of "Explore." However, the card set should show carbon moving and changing in ways that are DIFFERENT from the example.

Grades 3-5

Students can get ideas about how and why carbon moves and changes from the Carbon Cycle Game they play in the Explore section of Lesson 3 and choose an idea that is present in their local area or that impacts them. Their handouts from the carbon cycle game (Explain) may also be useful to show how carbon moved and changed.

Students can work individually, in pairs, or in small groups on this task.

After all students have a first draft, consider having students make and cut apart a copy of their card sort to see if their peers can recreate their carbon story by sorting and explaining the sequence of events. This should provide feedback and ideas on how they can make their carbon story more clear.

If you choose this option, skip the rest of the "Explain" section and go right to "Elaborate."

Carbon cycle diagram
https://www.usgs.gov/media/images/usgs-carbon-cycle

Every community is unique, but carbon and the carbon cycle happen everywhere. In this part of the lesson, students will work in small groups to create a placed-based carbon cycle model of their community.

How students define their community will vary, but it should cover a large enough geographic region to include the school, students' homes, and important industries in the community. Discuss how much of a geographic region to include in their models. Not all student groups need to agree on the same scale.

Middle School / High School
Say: Let's review what we've been doing so far in this lesson. First, we put some cards in order to tell a story about a tree. Then, we explored a carbon cycle game and made a fructose model about photosynthesis. Finally, made connections between the tree story, the carbon cycle, and the fructose model. Now, we are going to combine everything we have learned to represent our local carbon cycle, including the role of humans in our local carbon cycle.

SAY: The carbon cycle diagram (linked in the sidebar) doesn't represent a real place, and the goal of the diagram is to represent every possible reservoir and process in the world's carbon cycle. We are going to make our own representation of the carbon cycle that focuses on our community. Each group will create a "model" of our local carbon cycle. This could be a map, flow chart, infographic, or other representation. The word "model" just means that we are trying to represent the objects and connections in a system in some way.

The goal of our models is to answer the following list of questions. So, our first step is to be sure that we all understand the questions. Read Questions 1-3 and discuss them with your group. What ideas do you have about these questions? You don't have to have all of the answers right now--we are just trying to ensure that you have an understanding of the goals of the model and the questions.

1. What area does your model represent, how large is it, and how did you decide on that area for your model?
2. What "**reservoirs**" in the carbon cycle do you see (these are the same as the 9 station names from the game)? Label them.
3. What **processes** from the carbon cycle are likely taking place in this area, whether you can see them or not? How is carbon moving and changing in your area? Represent and label these processes.

Circulate as students discuss the first three questions. It may be helpful for them to consult a map of the local area (such as on Google Maps), their work from previous parts of the lesson, or a carbon cycle diagram (such as the one linked in the sidebar). After students have had some time to discuss Questions 1-3, bring the whole group together and ask if someone can explain each question in their own words, or if they need any clarification on what the question is asking. It is important for students to understand that parts of the carbon cycle game that are NOT present in our community should be left out of the model we are making. We are only representing local parts of the carbon cycle.

Then, move on to the Questions 4-6. Ask students once again to read and discuss these questions in their small groups to ensure that they understand what each question is asking.

4. How are **human activities** involved with the carbon cycle in our area? This might include agriculture, forestry, other industries, transportation, energy generation or use, etc. Are these activities moving more carbon around, or storing more carbon?
5. For the **reservoirs** in your model, are there some where carbon might be stored (ie, "get stuck") for a long time? Are there some where carbon is likely to move out quickly? How might you represent this in your model?
6. Consider how carbon might be crossing into or out of our area **across the boundaries** of your model. What are some ways that carbon might be going out of our area? What are some ways that carbon might be coming in? How will you represent this in your model?

Circulate as students discuss Questions 4-6. Again, the goal is to ensure that they understand what the questions are asking, not necessarily to have all of the answers. After students have had some time to discuss Questions 4-6, bring the whole group together and ask if someone can explain each question in their own words, or if they need any clarification on what the question is asking.

Once students are sure that they understand the questions and the task, they should work together to plan and create their local carbon cycle model to address all 6 questions. Make sure that they know that they may have to make several attempts before coming up with a model that makes sense and answers all of the questions. Younger students or those who lack experience with creating models may need reminders about adding labels and/or a legend or key. Let students know that they will have time to work on a draft, then they will share their draft with others before finalizing their work.

Some tips for guiding students to success in this task include:

- Consider starting with copies of a carbon cycle diagram (or several different representations of the carbon cycle that you find on line) and have students cross out reservoirs and processes that are NOT occurring in the local area. For instance, if you don't live near an ocean, there shouldn't be an ocean in your model!
- Students may also like to start with the carbon cycle game station cards, and consider which are important and which are lessons important to their area.
- It may also help students to start out with an underlying map or access to Google maps, where they can use street maps or satellite images to understand visible features like farms, forests, the ocean, etc.
- Encourage students to observe their local community on their way to and from school or otherwise walking or driving around.
- Internet research might be helpful.
- Community interviews might be another useful source of information. Municipal authorities, parents and families, and those who engage in outdoor work or recreation might have ideas about these questions. Consider "dividing and conquering," with each student or group interviewing one or two people and then sharing their answers with the whole class.

After students have a draft of their model, pair up groups, with one group starting as the "explaining" group and the other as the "listening" group. Have the "explaining" group use their draft model to explain the answers to the six questions to the "listening" group. Students should be able to point to items on their model that allow them to explain each answer. The "listening" group should ask questions and give feedback before switching roles. Students will then have more time to finalize their local carbon cycle models.

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Students should finalize their local carbon cycle models based on feedback from this share-out.
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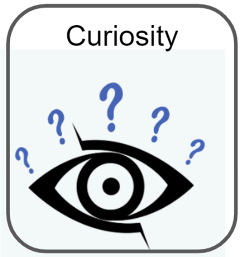
<td>
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If you started a Class Question Board in Lesson 1, now is a great time to refer back to it. Ask students:

What might these carbon and carbon cycle ideas have to do with Venus?
Are there other questions on our board that relate to these ideas?
What new questions do you have?

You should also refer back to the Class Question Board after the “Elaborate” portion of the lesson.
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<td>Elaborate
(90 Min)</td>
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Students will conduct research about Venus in order to create a Venus version of the carbon cycle game.
Give students access to the carbon cycle game station cards from the “Explore” part of this lesson. Students will also need access to computers in order to conduct research.
In this part of the lesson, students will use a variety of resources to take the Earth Carbon Cycle Game and create a Venus version of the game. Venus has carbon and a carbon cycle, but it is very different (and in many ways, much simpler) than Earth’s carbon cycle. Students may work on their own or in pairs or small groups for this part of the lesson.
Students should be able to justify all of the changes they make using the NASA sources provided or reliable sources they find on line. These sentence stems may be useful for students as they conduct research and make changes to the carbon cycle game.

I am removing <u>(process/reservoir)</u> from the game because Venus doesn’t have this. I know this because <u>(cite article, video, or other source for this knowledge).</u>
I am adding this carbon <u>(process/reservoir)</u> to the game because Venus has it but it isn’t represented in the Earth carbon cycle game. I know this because <u>(cite article, video, or other source for this knowledge).</u>
I’m changing (process/reservoir/other detail) from the game because it is different on Venus than on Earth. I know this because <u>(cite article, video, or other source for this knowledge).</u>

Even if students think they “know” something about Venus for sure (for example, that there is no life or no water), they should still be required to provide some evidence from one of the research sources.
Their final version of the game should include station cards for any station that exists on Venus. Each station card should include notes on what students should do depending on what number they roll on the dice. Just like with the Earth Version of the game, it is OK if the same action happens for more than one number on the dice, and it is OK if “stay in this station” is an action for one or more of the stations.
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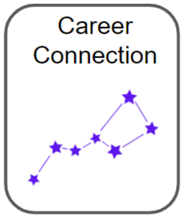
It is up to you if you would like to provide only vetted resources for students or if you'd like them to be able to freely find resources online. We have provided some resources below to help you get students started.

Grade Level Adaptation	**Research resources (videos, articles).** Preview these to decide which ones to provide to your students. For older students, consider encouraging them to find their own resources using good research and media literacy skills (corroborating sources, examining authorship, etc). **All Students** https://science.nasa.gov/venus/ https://www.youtube.com/watch?v=MAwtM_aq-1U (Ten Mysteries of Venus video) https://www.youtube.com/watch?v=z8HB8jlWai8 ("Why is Venus Called Earth's Evil Twin?") **Grades 3-5** https://spaceplace.nasa.gov/all-about-venus/en/ **Middle School and High School** https://science.nasa.gov/earth/climate-change/nasa-climate-modeling-suggests-venus-may-have-been-habitable/

When they have their first draft of the game and explanations ready, group students to share with one other student or group. They should compare and share their draft games and explanations and give each other feedback before finalizing their game.

Evaluate (45 Min)	***Students will document their work and learning for this lesson.*** This lesson has two main deliverables. Teams will either create a place-based carbon cycle OR a carbon cycle story card set. Additionally, all teams will create a Venus version of the carbon cycle game. Guidelines for these deliverables are below. **Place-based carbon cycle (1 per team, required for Middle and High School; optional for Grades 3–5, see below):** Create a visual representation of a place-based local carbon cycle. Not all elements of the whole Earth's carbon cycle will be present. (For example, unless you live near an ocean, you will not include this on your model.) This representation might be an annotated map, a flow chart, an infographic, or any other labeled visual representation that helps to answer these questions: ● What area does your model represent, how large is it, and how did you decide on that area for your model? ● Represent and label all reservoirs (lakes, rivers, clouds, etc.) and water cycle processes (evaporation, runoff, etc.). ● What **reservoirs** in the carbon cycle are present in your community? (Examples: ocean, plants, etc.) Label them. ● What **processes** from the carbon cycle are likely taking place in this area, whether you can see them or not? (Examples: photosynthesis, volcanoes, etc.) Represent and label them. ● How are **human activities** involved in your local carbon cycle? How are human activities causing carbon to move and change? Represent and label this on your model. ● For the **reservoirs** in your model, are there some where carbon might be stored (that is, "get stuck") for a long time? Are there some where carbon is likely to move out quickly? Represent this on your model. **Carbon Cycle Story Card Set (1 per team or 1 per student; this option is for Grades 3–5 only):** Instead of the place-based carbon cycle, teams in Grades 3–5 may create a Place-based Carbon Story Card Set. This card set should: ● Have a short title that reflects the overall story that involves a local part of the carbon cycle. ● Include 6–10 cards in a sequence that show carbon moving and changing. ● The carbon should move to a new reservoir at least twice and change form (solid, gas, liquid) at least once. ● Include a written or audio-recorded description of what is happening in the card set. ● This card set should be modeled after the card set and description in Lesson 3 (Engage and Explain). However, the card set should show carbon moving and changing in ways that are different from the example. Students can get ideas about how and why carbon moves and changes from the Carbon Cycle Game they play in the Explore section of Lesson 3. **Venus Carbon Cycle Game and Justification (1 per team, all grades):** Use the Carbon Cycle Game for Earth as inspiration to create a game that represents the carbon cycle on Venus. Your game should include: ● Station cards that represent carbon reservoirs and show where carbon is stored on Venus. ● On each station card, show processes or actions that can move carbon on Venus from one reservoir to another. ● A justification for the changes made to the Earth Carbon Cycle Game that led to your completed Venus Carbon Cycle Game. This can be a narrative explanation or a series of bullet points. ● Areas of the game where you were not sure or had to make assumptions.	

Extend (Optional)	***Students will investigate NASA careers related to the work of this lesson.***	



There are several NASA careers related to this lesson featured in the table below. Explore them all to learn about the people at NASA that could achieve this Mission Objective!

After reviewing the featured jobs, ask students to pick out key words or phrases that are related to this job or things that interest them about this job. Create a word cloud or keep this list.

You might like this career if you liked….	Job Title	Link to Resource	Type (reading, video, etc)	Recommended grade bands
If you liked playing the carbon cycle game…	Planetary Scientist	Career Spotlight: The Plan…	Video (2:39)	3 - 12
If you liked playing the carbon cycle game…	Planetary Geologist (Petrologist)	Dr. Justin Filiberto	Personal website	6 - 12
If you want to know more about processes on other planets…	Director, Lunar and Planetary Institute	Dr. Walter Kiefer	Profile / Bio	6 - 12
If you liked the fructose model…	Project Scientist (Atmospheric physics)	JPL Science: Vivienne Payne	Profile / Bio	6 - 12
If you liked the fructose model…	Research Scientist (Geochemistry)	JPL Science: Amy Hofmann	Profile / Bio	6 - 12
If you want to know more about processes on earth…	Climate Researcher	Day in the Life of a climate researcher - YouTube	Video (0:49)	3 - 12
If you liked creating a Venus carbon cycle game…	Research Scientist, Aerobiology	A conversation with Diana Gentry.	Audio interview (28:39)	9 - 12

Carbon Cycle Game (Teacher Instructions)

This game is played twice during “Explore.” You may choose to play the game several ways, which are described in the table below. NOTE! This is not a game where students “take turns.” All students can be rolling their dice, recording, and moving. At the same time.

- **Before you begin:** see Teacher Guide for how to prepare students for the game.
- **Between rounds:** see Teacher Guide for Reflection and Discussion ideas.
- **After Round 2:** see Teacher Guide for Reflection and Discussion ideas.

Type of Gameplay / Materials	How to Play
We recommend: Whole-class kinesthetic model 10 full-sheet station cards (including two “Fossil Fuel” cards) Dice (1 per student) or virtual dice Student recording sheets (1 per student, different sheets for Round 1 and Round 2	**Set-Up**: Hang the 9 station cards around the room (keep the Fossil Fuel Round 2 card out for now.) Make sure students have a Round 1 handout. Start 1 student at each station except for sedimentary rocks--all other students start in the sedimentary rocks. (Why? Because the rocks store over 90% of Earth’s carbon!) **Round 1:** (Use the “Fossil Fuel” Station Card for Round 1). Students roll their dice, record the station they are moving to on their sheets, and move accordingly. Record their new station on the next line as “Start at…”, roll, and repeat. They should repeat this process 10 times, recording as they go. **Round 2:** (Use the “Fossil Fuel” Station Card for Round 2). Before beginning play, ask students to compare and contrast the two Fossil Fuel cards. Have them discuss what they notice, what the model is trying to show, and how they predict this will impact the game. Then, they should play the game as before, recording on the Round 2 sheet.
Online Slides Version Laptops (1 per student) Dice (1 per student) or virtual dice Student recording sheets (1 per student, different sheets for Round 1 and Round 2)	Each student must have their own device (laptop) and be able to access Google Slides. Start 1 student at each station except for sedimentary rocks--all other students start in the sedimentary rocks. (Why? Because the rocks store over 90% of Earth’s carbon!) Make sure they know that each student will have a unique path--they are not all recording the same thing. **Round 1:** (Use the Carbon Cycle Game (Round 1) file). Students roll their dice, record the station they are moving to on their sheets, and move accordingly on the instructions on slides. Record their new station on the next line as “Start at…”, roll, and repeat. They should repeat this process 10 times, recording as they go. After students finish 10 rounds, they should group up into groups of about 4 students and discuss the reflection questions (see lesson plan). **Round 2:** (Use the Carbon Cycle Game (Round 2) file). Before beginning play, ask students to compare and contrast the two Fossil Fuel cards. Have them discuss what they notice, what the model is trying to show, and how they predict this will impact the game. Then, they should play the game as before, recording on the Round 2 sheet.

The table corresponds to the station cards and is **provided for the teacher only**.

Fossil Fuels (Round 1)		
Roll	**Next Station**	**Process**
1, 2, 3, 4, 5	Fossil Fuels (Stay)	You stay buried deep underground for a very long time.
6	Atmosphere	A little carbon leaks out through cracks or volcanoes.
Fossil Fuels (Round 2)		
Roll	**Next Station**	**Process**
1, 2, 3	Fossil Fuels (Stay)	You stay buried deep underground for a very long time.
4, 5	Atmosphere	People dig you up and burn you, sending you into the air as CO_2.
6	Atmosphere	A little carbon leaks out through cracks or volcanoes.
Atmosphere		
Roll	**Next Station**	**Process**
1, 2	Atmosphere (Stay)	You stay in the air as CO_2 for now.
3, 4	Surface Ocean	You dissolve into the surface of the ocean.
5	Plants on Land	A plant pulls you out of the air during photosynthesis.
6	Soils	Rain carries you into the soil.
Plants on Land		
Roll	**Next Station**	**Process**
1, 2	Atmosphere	The plant breathes out CO_2, sending you back to the air.
3, 4	Soils	The plant dies and rots, so you move into the soil.
5	Plants on Land (Stay)	You stay inside the plant for now.
6	Animals and Fungi	An animal or fungus eats the plant and takes you in.

Animals and Fungi		
Roll	**Next Station**	**Process**
1, 2, 3	Atmosphere	Breathing sends you back to the air as CO_2.
4, 5	Soils	Waste or dead bodies rot, so you move into the soil.
6	Animals and Fungi (Stay)	You stay inside the animal or fungus for now.

Soil		
Roll	**Next Station**	**Process**
1, 2	Soils (Stay)	You stay stored in the soil for now.
3	Atmosphere	Decomposers break things down and release you to the air as CO_2.
4	Plants on Land	Plant roots take you up from the soil.
5	Fossil Fuels	Over millions of years, deep burial turns you into fossil fuels.
6	Sedimentary Rocks	More burial and squeezing change you into rock.

Surface Ocean		
Roll	**Next Station**	**Process**
1, 2	Surface Ocean (Stay)	You stay dissolved in the sunlit ocean water.
3	Atmosphere	You bubble out of the ocean back into the air.
4	Ocean Plants and Animals	Ocean plants or animals take you in.
5	Deep Ocean	Currents carry you down to deeper water.
6	Sedimentary Rocks	Mud on the sea floor traps you and hardens into rock.

Ocean Plants and Animals		
Roll	**Next Station**	**Process**
1, 2	Ocean Plants and Animals (Stay)	You stay inside ocean plants or animals for now.
3	Surface Ocean	Breathing or waste puts you back into the surface water.
4	Deep Ocean	The dead organism sinks, taking you deeper.

5	Sedimentary Rocks	Shells and bones pile up and turn into rock.
6	Atmosphere	You return to the air as CO_2.
Deep Ocean		
Roll	**Next Station**	**Process**
1, 2, 3	Deep Ocean (Stay)	You stay dissolved in deep water for a long time.
4	Surface Ocean	Upwelling brings you back toward the surface.
5	Ocean Plants and Animals	Deep-sea creatures take you in.
6	Sedimentary Rocks	Sea-floor mud locks you into rock for the long term.
Sedimentary Rocks		
Process	**Next Station**	**Process**
1, 2, 3	Sedimentary Rocks (Stay)	You stay trapped in rock—the slowest part of the cycle.
4	Fossil Fuels	Rarely, heat and pressure turn some rock carbon into fossil fuels.
5	Atmosphere	Weathering or volcanoes releases you to the air as CO_2.
6	Soils	Erosion moves you from rock into the soil.

Fructose Model - Teacher Directions

Material Prep
Quantities are listed below for ONE molecule. We recommend 2-3 students work together on one molecule. So, prepare accordingly for your group size.

- Prepare 12 molecules in baggies
  - Make 6 H2O molecules by placing two H (white/clear) bingo chips and one O (red) bingo chip into a baggie.
  - Make 6 CO2 molecules by placing one C (black/grey) bingo chip and two O (red) bingo chips into a baggie.
- Print 1 fructose card

Facilitating This Activity

1. Once the class has established which molecule is which, you have to main options on how to proceed:
   a. For younger students, it is a good idea to "construct" a fructose molecule as a class. Ask pairs of students (one with a water molecule and one with a carbon dioxide molecule) to come up, break the bonds (open the baggie), and place the correct atoms (bingo chips) in the labeled spots of the card. Continue to bring up more pairs of students to fill the fructose card. What they will notice is that there is "no place" for the extra oxygen atoms. What happens to the extra (waste) oxygen? It is released into the atmosphere. You can place these around the card, but off the edge. Don't worry about the idea that all oxygen atoms "pair up" as this is not as critical for younger students.
   b. For older students, consider doing only one round of molecules as described above, and then asking them what they will need to construct the entire fructose model.
2. Regardless of which option you follow above, students should come to the conclusion that 6 water molecules and 6 carbon dioxide molecules are needed to make one fructose model, with 12 atoms of oxygen left over.

Extension Options

- Here are two videos to show how widespread the alternative conceptions about where plants get their mass. Consider showing these after students have grasped the ideas themselves.
  - Veritasium video: https://www.youtube.com/watch?v=2KZb2_vcNTg
  - MIT Video https://www.youtube.com/watch?v=JhCHb6xtqeY
- **Compare and contrast the "Carbon Moving and Changing" model with the Fructose Photosynthesis model. Ask questions such as:**
  - What is the time scale of each model? What is the size scale of each model?
  - What role did students play in each model, and how is it different (in "Fructose" students represent the sun, in the "Carbon Moving and Changing" they represent the carbon atom).
  - How are the two models related?

    - Where is fructose being made in the carbon cycle game? (when carbon is leaving the atmosphere station and moving to the plants station, or when carbon is leaving the surface ocean station and moving to ocean plants and animals station)
- **Burn it up, Metabolism.** The reverse reaction of photosynthesis is combustion. After you have made your fructose models, ask what it means to "burn calories" when we eat sugar. Why do we burn calories? Do we burn more calories during exercise? What else do you notice when you exercise (you breathe a lot harder, perhaps sweat, get tired, etc). Reversing the photosynthesis reaction explains some of these responses. More oxygen is needed, we burn the sugar (release stored energy from the sun), exhale CO2 and water. Students may also say that sweat is because water is being released in the reaction, and while this is not the best explanation (sweating is an attempt to cool down the body from the heat of the reactions), there is evidence in the chemical equation to suggest this as a possible explanation.
- **Burn it up, Forest Fires.** The reverse reaction of photosynthesis is combustion. When plants die, the energy is still stored in their materials. If plants die over years and years and build up on the forest floor and in the forest soil, a lot of carbon is stored there. If a forest fire comes through and burns all those years of dead plant material at once, what happens? Where does the carbon go? Students could apply this understanding to the "Carbon Moving and Changing" Model. What would happen if there were a lot more forest fires? What would happen if there were fewer forest fires? Which station cards in the model would need to change?
- **Other molecules?** Consider ways to use the mini ping pong balls and trays to model other chemical reactions, particularly for high school students. Keep in mind that you will need different molecule cards to get the correct number of molecules in the final product.

Context

Students may have had previous learning experiences that bring up the idea that plants need water and sunlight to grow. They may or may not have had previous experience with carbon dioxide as a necessary ingredient for plant growth.

Upper elementary students might engage in this activity as an advanced life science exploration involving plants. 5-PS3-1 (animals' energy was once from the sun), 5-LS1-1 (plants mainly need air and water), and 5-LS2-1 (movement of matter through the environment) are the main standards. 5-ESS2-1 is a supporting standard. The MySci unit above is a 5th grade unit and has more ideas for work in this area.
Middle school students may engage in their study of MS-LS1-6 (photosynthesis). This activity also supports MS-PS1-5 (conservation of mass). MS-LS2-3 (cycling among living and non-living).
High school students might engage in this activity during their study of HS-LS2-5 (photosynthesis) and/or HS-ESS2-6 (carbon cycle). In addition, connections can be made to HS-ESS3-6 (human impacts) and HS-PS1-7 (conservation of mass).