Stability of the Solar System 5E

Stability of the Solar System 5E	Why do we see so many craters on other objects in our solar system, but not on Earth? What was the solar system like in the past?	**Performance Expectations** HS-ESS1-6, HS-ESS2-5	**Investigative Phenomenon** On Earth, the number of impact craters discovered is around 128. On Mars, the number is more than 300,000. On the Moon, the number is more than one million!	**Time** 7-8 days

In this 5E instructional sequence, students are investigating their questions about how often asteroids have struck Earth in the past, how asteroid impacts affect Earth, and what the solar system was like in the past.

Engage	How often have asteroids struck Earth? Can asteroid impacts explain why it took so long for intelligent life to evolve on Earth?	Looking for evidence of **stability and change** in the **solar system**, students **examine images** of **Mars, the Moon and Earth** and look for patterns in the **existence of craters** in order to **develop initial claims** for why, despite the fact that the **oldest minerals in all three locations are about the same age, there are so few craters on Earth**.
Explore 1	What can the composition and age of rocks from objects in the solar system tell us about its past?	Students **collect data** related to the **age, composition and density of rocks** on the Earth, Moon, and other solar system objects in order **to make and support claims** for why **craters on other solar system objects** remain **stable and craters on Earth change**.
Explain 1	How old are the solar system and the impact craters?	Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and **scientific reasoning to explain** the age of the solar system and the timing of the great heavy bombardment despite the **changes to Earth's surface**.
Explore 2	How do the properties of water affect the persistence of impact craters on Earth?	Students **plan and conduct an investigation** into the properties of water to explore how the **molecular structure of water** and its **physical and chemical properties influence the planet's dynamics** and the persistence of impact craters on Earth's surface.
Explain 2	What explains the tremendous difference in the number of craters on the Moon, Mars, and Earth?	Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and the **molecular structure of water** as they relate to **the hydrologic and geologic** cycles **to develop a model** of the **early solar system** and use what they know about **natural destructive processes** to **explain** why **craters on other solar system objects** remain **stable and craters on Earth change**.
Elaborate	How has the Rock Cycle Impacted the Stability of Craters on Earth?	Students use their understanding of **stability and change** to **apply scientific reasoning to assess the extent to which the data support claims** about **active geological processes interrupting the record of asteroid impacts** on Earth.
Evaluate	How might asteroid collisions affect the probability of life evolving?	Students **develop an explanatory model** for how **asteroid collisions with Earth** have impacted **stability and change** of **Earth's systems** and the role they have played in the **evolution of life on Earth**, then use it to **make and defend an argument** about whether life or intelligent life exists somewhere outside Earth.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

How often have asteroids struck Earth? Can asteroid impacts explain why it took so long for intelligent life to evolve on Earth?

Looking for evidence of **stability and change** in the **solar system**, students **examine images** of **Mars, the Moon and Earth** and look for patterns in the **existence of craters** in order to **develop initial claims** for why, despite the fact that the **oldest minerals in all three locations are about the same age, there are so few craters on Earth**.

Preparation

Student Grouping	Routines	Literacy Strategies
None	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Craters in the Solar System	None	

Launch and Surfacing Student Ideas

1. Remind students that, during the Driving Question Board launch, one category of questions that emerged was related to asteroid impacts, such as: *How often have asteroids struck the Earth in the past?* and *Can asteroid impacts explain why it took so long for intelligent life to evolve on Earth?*

2. Use students' questions to transition to the guiding questions: *What can we learn about the history of Earth and our solar system? How frequently did asteroids hit the Earth in the past?*

3. Ask students the following questions:

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. In the Engage phase, it is often used to surface student ideas that can

- In past science classes, in what ways have you investigated the history of Earth?
- What can we observe and investigate on Earth and / or on other objects and planets that might provide clues about how often asteroids struck Earth in the past?

Support students in responding to these questions by encouraging them to think about what evidence of asteroid impacts exist on Earth and to consider images they have seen of the Moon and Mars and recall what they have observed in these images that might be evidence of asteroid collisions. Have a few students share their ideas.

be used to transition the class to the investigation.

Look & Listen For

Possible student ideas and questions that can be used to transition to the next steps:

- I remember hearing / seeing that there are big craters on Earth that are evidence of an asteroid impact.
- When I've seen images of the Moon or Mars they both have craters on them.
- I have seen craters on the moon when it's very visible at night.
- We can investigate how many craters are in different places in our solar system including Earth.

4. Tell students that studying rocks from Earth and other solar system objects and asteroid impact craters are a couple of the ways scientists attempt to reconstruct the history of our solar system and better understand the evolution of life on Earth.

5. Let them know that they will now have a chance to conduct these types of investigations themselves in order to answer their questions about whether asteroid impacts can help explain why it took so long for life to evolve on Earth. Provide students with the handout, *Craters in the Solar System*, and ask them to work independently as they complete the See-Think-Wonder based on data and their observations of craters on Mars, the Moon, and Earth, then use these completed pages to discuss the findings from the investigation.

6. Ask groups to come up with one important idea to share with the whole class, from their See-Think-Wonder.

7. Use the group learning routine Domino Discover to surface important trends, inferences, and questions from groups' Summary sections.

Look & Listen For

Possible student ideas and questions that can be used to transition to the next phase(s):

- There are a lot of craters all over the Moon, some on Earth, and a lot on other objects like Mars.
- The Moon has almost 10,000 times the number of craters as Earth and more than 3 times the number of craters as Mars.
- The craters on the Moon and Mars seem to be bigger and deeper.
- I think more asteroids have hit the Moon than Mars and Earth, that's why there are so many craters.
- I think maybe Mars has existed longer than the Earth and the Moon has existed longer than Earth.
- Why don't we see so many craters on Earth?
- How long ago did planets and moons in the solar system form? Did they all form at different times or at the same time?

8. Tell students that they will now have the opportunity to investigate their questions by analyzing and interpreting age and composition data from several objects in the solar system.

Explore 1

What can the composition and age of rocks from objects in the solar system tell us about its past?

Students **collect data** related to the **age, composition and density of rocks** on the Earth, Moon, and other solar system objects in order **to make and support claims** for why **craters on other solar system objects** remain **stable and craters on Earth change**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Early Solar System Investigation	None	❑ Radioactive Dating Game - Radiometric Dating | Carbon Dating | Half Life - PhET Interactive Simulations

Launch

1. Remind students about their ideas and questions regarding what the solar system was like in the past, when planets and objects formed and what they're composed of. Have a few groups share their ideas.

2. Tell students that they will first start by developing an understanding of how the composition of rocks and other matter on Earth can be used to determine the age of those rocks and matter, then they will use what they learn to determine the age of rocks from different planets objects.

Investigation: Early Solar System

1. Provide each student with the *Early Solar System Investigation* handout.

2. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Note: for New York State Teachers, the Geologically Important Radioactive Elements Used for Radiometric Dating table comes from page 15 of the ESSRT.

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:

Part 1a

- What patterns do you notice in how fast Carbon-14 changed? Was it always the same?
- What patterns do you notice in how fast Uranium-238 changed? Was it always the same?
- What do you notice was different about how fast the two isotopes changed?

Part 1b

- What pattern do you notice in the age of the fossils within the same rock layer?
- What pattern do you notice in the age of objects as you go into lower rock layers?
- What do you notice about the isotope needed to age each object?

Part 2

- What do you notice about the age of minerals of different objects in the solar system?
- What does this make you think about when the Earth and other objects were formed?
- What do you notice about tectonic activity on different objects in the solar system?
- What do you notice about the existence of water and an atmosphere on different objects in the solar system?
- Do you think this might relate to the number of impact craters we observe in different objects in the solar system? If so, what? How?

Part 3.

- What do you notice about the age of the melt rocks in the moon craters?
- Do these craters make you think about the craters on Mars and Earth? What questions do you have about those craters?

Integrating Three Dimensions

In this unit students are continuing to develop proficiency with proficiency with **CCC#6 Stability and Change**, specifically the idea that much of science deals with constructing explanations of how things change and how they remain stable. The ideas about carbon-14 and uranium-238 changing to different elements are an important part of supporting students in understanding this crosscutting concept.

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the See-Think-Wonder section, then use these completed pages to discuss the findings from the investigation.

2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.

3. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence.

Look & Listen For

These observations and ideas are critical to students' success during the Explain phase:

- 50% of carbon-14 changes into nitrogen-14 about every 5700 years.
- 50% of uranium-238 changes into lead-206 about every 4.5 billion years.
- Carbon-14 changes / decays much faster.
- Fossils in lower rock layers are older than fossils in higher rock layers.
- You need different isotopes to age things that are different ages. Uranium-238 is better for older stuff because it takes longer to decay and carbon-14 is better for younger stuff because it decays faster.
- Uranium-238 works if the rocks contain Uranium-238; Carbon-14 works only for samples containing organic materials, glacial ice containing carbon dioxide, groundwater, and ocean water.
- The ages of the objects in our solar system data table fall between 4.40 and 4.59 billion years ago. They are all pretty close in age.
- I think this tells us that the solar system formed within that time frame. Earth's crust must have formed about 4.4 billion years ago
- Differences in age don't seem to explain differences in the amount of craters observed because the Moon has way more craters than Mars and Earth, but formed after Mars and around the same time as Earth.
- The age of impact melt rocks from moon craters range from 3.75 to 4.0 billion years ago.
- This makes me think that there were a lot of asteroids hitting the moon 3.75 to 4.0 billion

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Earth & Space Science Course Guide for support with this routine.

Access for Multilingual Learners

Using **Domino Discover** at this stage provides support for multilingual learners who are **emerging** and **transitioning**. Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development. Refer to the Earth & Space Science Course Guide for more information on this routine.

years ago.

These questions or similar questions can be used to transition to the next phase(s):

- If Mars, Earth and the Moon were formed around the same time and they all existed when so many asteroids were impacting, why does the moon have so many more craters?
- If a huge number of asteroids were hitting the Moon 3.75 to 4.0 billion years ago, wouldn't they have hit Mars and Earth too?

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Explain 1

How old are the solar system and the impact craters?

Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and **scientific reasoning to explain** the age of the solar system and the timing of the great heavy bombardment despite the **changes to Earth's surface**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Triads	❑ Think-Talk-Open Exchange ❑ Class Consensus Discussion	❑ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❑ Explaining the Craters in the Inner Solar System ❑ Summary Task	None	❑ The Main Asteroid Belt ❑ The Late Heavy Bombardment

Launch

1. Remind students that during the Explore phase they figured out that the Moon, Mars, and Earth all formed around the same time, so the amount of time they have existed cannot explain the differences in the number of craters. Also highlight the impact melt rock found in or near the large majority of craters on the moon and let students know that scientists have proposed a theory about the early solar system based on this evidence.

2. Tell students they will have a chance to learn about this theory and how it would have affected the Earth and other inner solar system bodies.

Developing Models

1. Provide students with the handout: *Explaining the Craters in the Inner Solar System*. Have students work in triads to answer the 6 questions on the first page.

2. When students are done, have them turn to the short text and use the learning routine Think-Talk-Open Exchange to share their ideas about the evidence for the Late Heavy Bombardment and its possible effects on life.

3. For additional context, show the video, The Late Heavy Bombardment .

4. Ask students to work in their groups to respond to the prompt "what was the early solar system like, and what can we infer about the history of life on Earth based on that?"

Look & Listen For

These or similar questions and ideas can be used to transition to the next phase(s):

- I think that the Earth and Mars must have had a really high number of craters since they would have been hit by a lot of asteroids during the Late Heavy Bombardment.
- Why don't we have rocks from Mars that prove that?
- Where are the craters on Earth?

Integrating Three Dimensions

In this unit students are developing proficiency with the **SEP#6 Constructing Explanations & Designing Solutions**, specifically applying scientific reasoning and / or models to link evidence to claims to assess the extent to which reasoning and data support an explanation or conclusion, an important element of **SEP#6 Constructing Explanations & Designing Solutions** at the high school level.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:
   - "We are going to use a **class consensus discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to consensus about what the early solar system was like.

Class Consensus Discussion Steps

1. we select a few different groups' ideas.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all

2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

2. Select two or three student explanations to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of when the solar system formed and how asteroids impacted inner solar system bodies. The decision about which explanations to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

3. Ask the first student or group to share their explanation. You can do this by:
    - Projecting using a document camera; OR
    - Copying the written explanation to be shared and passing them out to the class; OR
    - Taking a picture of each explanation and projecting them as slides.

- Proceed through the steps in the Consensus Discussion Steps.

- Before table groups confer, prompt them to consider the role of understanding stability and change in constructing an understanding of the history of our solar system. Some prompts you might provide are:
    - As we figured out details about the history of our solar system, why was it important to understand stability and change of:
        - isotopes like Carbon-14 and Uranium-238?
        - surfaces on the Moon, Mars, and Earth?
    - How has the stability of the solar system changed over time?
    - How do you think asteroid bombardments affected stability and changes to life on Earth?

5. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk.

students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Please read the Earth & Space Science Course Guide for detailed steps of this routine.

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **SEP#6 Constructing Explanations & Designing Solutions** explicit for students by probing and elevating ideas related to applying scientific reasoning and / or models to link evidence to claims to assess the extent to which reasoning and data support and explanation or conclusion. The Conferring Prompts about evaluating how well evidence supports claims can be useful here.

Integrating Three Dimensions

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:

- The solar system and Earth formed about 4.5 billion years ago
- Evidence for the age of the solar system comes from using radiometric dating of rocks from the moon, Mars, and Earth
- The late heavy bombardment occurred about 4 billion years ago
- Evidence for the age of the bombardment comes from radiometric dating of melt rocks on the moon
- The bombardment likely affected Mars and Venus due to the presence of craters on those planets
- Because Earth is near these other celestial bodies, the late heavy bombardment likely affected it as well, even though the craters are no longer present

The Class Consensus Discussion prompts about stability and change are meant to seed the idea that much of science deals with constructing explanations of how things change and how they remain stable, an important element of **CCC#7 Stability & Change** at the high school level. This idea will help students respond to questions about why it took so long for intelligent life to evolve on Earth and the probability of intelligent life elsewhere.

6. Return to student questions from the Driving Question Board about the atmosphere, such as:
   - What makes Earth different from other planets?
   - Do other planets have water? Is water needed for life?

7. Ask students if any new questions have arisen from this investigation that they'd like to add to the board, such as:
   - Why don't we have evidence of the age of the craters on Mars?
   - Why don't we have more craters on Earth?

Summary

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about why Earth shows differences in its craters compared to other planets and the moon, despite their shared histories.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas: 1) **understanding how they are using the three dimensions, to make sense of a phenomenon** 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Explore 2

How do the properties of water affect the persistence of impact craters on Earth?

Students **plan and conduct an investigation** into the properties of water to explore how the **molecular structure of water** and its **physical and chemical properties influence the planet's dynamics** and the persistence of impact craters on Earth's surface.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ The Role of Water	❑ Two pieces of chalk or calcium carbonate tabs ❑ White vinegar ❑ Water ❑ Two clear cups ❑ Masking tape ❑ Stopwatch ❑ Goggles ❑ Forceps ❑ Electronic balance ❑ Stream table ❑ Fine sand ❑ Coarse sand ❑ Gravel ❑ Ring stand and clamp(s) ❑ Spray bottle ❑ Stream table dividers	

- ❑ Ruler/meter stick/measuring tape
- ❑ 2L soda bottle with the bottom cup off and a hole in the top of a plastic cup with holes in the bottom
- ❑ Round object for making craters in the stream table

Launch

1. Remind students that they had left Explain 1 wondering why, if Earth experienced the Late Heavy Bombardment at the same time as the moon and Mars, there isn't evidence of craters from 4 billion years ago
2. Tell students that there are several differences between Earth and the moon and Mars. Ask students to brainstorm some ways that they think Earth might be unique.

Look & Listen For

Possible student ideas and questions:

- Earth has oxygen
- Earth has living things
- Earth has water
- Earth is the right distance from the sun for life
- Earth has tectonic activity

3. Tell students that all of the differences they raised are important, and that they have already learned about some of those differences, but haven't discussed the others. Tell them that in this case, they are going to have the opportunity to investigate how water has impacted Earth's surface to see if it helps us understand why Earth has less evidence of craters than the moon and Mars do.

Investigation: The Role of Water

1. Provide students with the handout *Early Solar System Investigation*.

2. Tell students that they will be designing and completing an investigation into the role that water plays in Earth's processes.

Integrating Three Dimensions

3. Provide students with the materials for Part 1, and have students work in groups to perform Part 1. Chemical Weathering.

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:

- Can you think of any times that acidic liquid might fall on Earth, or on craters in the past?
- How do you think the chalk is similar or different from rocks on Earth?
- What do you think would happen to rocks on Earth if acid were poured on them?

In this unit students are beginning to develop proficiency with proficiency with **SEP#3 Planning and Carrying Out Investigations,** specifically determining how to design an experiment aligned to the purpose of the investigation and assign appropriate parameters for the experimental design in order to collect relevant data.

4. When students are done, pause the class to discuss the effects of acid on minerals. Help students draw connections between this investigation and their questions about craters on Earth.

5. Tell students that they will be designing an experiment for Part 2 of this investigation

6. Provide students with their options for materials, and have them work in groups to plan and design their experiments.

Implementation Tip

It may have been a while since students were tasked with designing experiments. Refer back to Unit 3, in which students designed an investigation to test the effect of surface color on the heat absorbed by the container, when they learned about albedo. Prompt students to remember the parts of an investigation, including reviewing the concepts of independent and dependent variable, hypothesis, and experimental design.

7. When students are done with their designs, check and approve them before allowing students to collect their materials and assemble their stream tables.

8. Confer with students as they complete their investigations

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:

- How is water impacting the surfaces on the stream tables?
- How are different surface types responding differently to the water?
- How does the moisture level of the surface affect its response to water?
- How do you think these processes might relate to what happened to the craters on Earth?

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the See-Think-Wonder section, then use these completed pages to discuss the findings from the investigation.

2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.

3. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence.

Look & Listen For

Possible student ideas and questions:

- Acidic water causes chemical weathering that breaks down Earth materials, like chalk
- Water causes physical weathering and erosion
- Chemical weathering, physical weathering, and erosion could have caused craters from asteroid impacts to erode

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Earth & Space Science Course Guide for support with this routine.

Access for Multilingual Learners

Using **Domino Discover** at this stage provides support for multilingual learners who are **emerging** and **transitioning**. Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development. Refer to the Earth

& Space Science Course Guide for more information on this routine.

Explain 2

What explains the tremendous difference in the number of craters on the Moon, Mars, and Earth?

Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and the **molecular structure of water** as they relate to **the hydrologic and geologic** cycles **to develop a model** of the **early solar system** and use what they know about **natural destructive processes** to **explain** why **craters on other solar system objects** remain **stable and craters on Earth change**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❑ The Role of Water ❑ Summary Task	None	

Launch

1. Remind students that during the Explore 1 phase they figured out that the Moon, Mars, and Earth all formed around the same time, so the amount of time they have existed cannot explain the differences in the number of craters. Also remind students that they have already concluded that Earth likely was affected by the Late Heavy Bombardment, but we were wondering why Earth didn't have more evidence of those impact craters.

2. Ask students to reflect on the investigation they just completed. Prompt students to share how water affected surfaces and minerals in their investigations, and to hypothesize how that might have affected the stability of Earth's craters.

Integrating Three Dimensions

In this unit students are developing proficiency with the **CCC#6 Structure and Function** specifically connecting the molecular structure of water to its function as a solvent in the water cycle.

3. Ask students to share their ideas about why the surface of Earth looks so different compared to the moon or mars surface.

Look & Listen For

- I think Earth's craters could have been worn away by erosion from water
- I think Earth's craters might have been dissolved by acid in chemical weathering

Constructing Scientific Explanation

1. Provide students with the handout, *The Role of Water*. Tell students that they will now have a chance to read a text that will help them understand if processes like the ones they described can help explain the differences in the number of craters found on Earth, Mars, and the Moon.
2. Have students read the texts, *The Role of Water* and *The Presence of Water in the Inner Solar System*, annotating for information that relates to the questions: *What can help explain the differences in the number of craters on the Moon, Mars, and Earth? Would you expect Earth-like levels of weathering, erosion, and deposition on Mercury, Mars, or the moon?*
3. After students have finished reading the texts, have them turn to a partner and share the information they annotated in response to the guiding question. Then use the group learning routine, **Domino Discover**, to surface ideas from each pair.

Integrating Three Dimensions

Use the Conferring Prompts to support students' evaluation of how well the evidence supports their claims about the differences in the number of craters on the Moon, Mars, and Earth, in service of the foregrounded element of **SEP#6 Constructing Explanations & Designing Solutions**.

Look & Listen For

- Mercury, Mars, and the Moon have only trace or small amounts of water.
- The structure of water helps it dissolve carbon dioxide, creating acidic rain that can cause chemical weathering on Earth like we saw in the investigation
- Water also causes erosion, which would damage craters on Earth
- Natural processes like chemical weathering and erosion from water could not have eroded, destroyed, or covered the craters on these places, explaining why we see so many more craters on their surfaces.

4. Tell students that they will now have an opportunity to use the evidence they have gathered so far to

construct a scientific explanation for the difference in the number of craters that are observed on the Moon, Mars, and Earth. Remind students that an important part of constructing a strong scientific explanation is including scientific reasoning that links evidence to the claim, and that they will have an opportunity to evaluate the extent to which data and scientific reasoning support their explanations.
5. Ask students to independently write a scientific explanation in response to the question: *Why is there a tremendous difference in the number of craters found on the Moon, Mars, and Earth?* and then evaluate the extent to which data and scientific reasoning support their explanations.
6. Confer with students as they write and evaluate their explanations. .

Conferring Prompts

- Does more than one piece of evidence support the claim?
- What scientific reasoning links each piece of evidence to the claim?
- Does the way you wrote this make the link between evidence and your claim clear to someone who reads it?
- Have you included any evidence that you are struggling to link to the claim through scientific reasoning? Why?

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:
   - "We are going to use a **class consensus discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to consensus about what the the early solar system was like and why we see a big difference in the number of craters on the Earth compared to objects like the Moon, Mercury, and Mars.

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

2. Select two or three student explanations to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of when the solar system formed, how stable it was, and why we see differences in craters across solar system objects. The decision about which explanations to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

3. Ask the first student or group to share their explanation. You can do this by:
    - Projecting using a document camera; OR
    - Copying the written explanation to be shared and passing them out to the class; OR
    - Taking a picture of each explanation and projecting them as slides.

- Proceed through the steps in the Consensus Discussion Steps.

- Before table groups confer, prompt them to consider the role of understanding stability and change in constructing an understanding of the history of our solar system. Some prompts you might provide are:
    - As we figured out details about the history of our solar system, why was it important to understand stability and change of:
        - isotopes like Carbon-14 and Uranium-238?
        - surfaces on the Moon, Mars, and Earth?
    - How has the stability of the solar system changed over time?
    - How do you think asteroid bombardments affected stability and changes to life on Earth?
    - How do you think the structure of water affected stability and changes to life on Earth?

5. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk.

Take Time for These Key Points

have from investigations, their models and texts in order to figure out and state those important ideas. Please read the Earth & Space Science Course Guide for detailed steps of this routine.

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **SEP#6 Constructing Explanations & Designing Solutions** explicit for students by probing and elevating ideas related to applying scientific reasoning and / or models to link evidence to claims to assess the extent to which reasoning and data support and explanation or conclusion. The Conferring Prompts about evaluating how well evidence supports claims can be useful here.

Pause the discussion and ask for clarification, particularly of the following key points:

- The fact that oldest minerals on the Earth, the Moon, Mars, and other solar system objects are about the same age (~4.5 BYA) and the similarities in their composition indicate these objects formed at the same time from the same disk of dust.
- If the Moon, Mars, and other solar system objects were being bombarded by asteroids, the Earth must have been bombarded as well since it is so close to the other objects. There were a lot of collisions in the early solar system.
- The Earth is the only of the objects with craters that has a significant amount of water. These processes that water is involved in change the surface of Earth a lot, so that can explain why we see so few craters on Earth compared to other solar system objects. The moon, Mars, and Mercury do not have nearly as much water, so they are not subject to the same types of chemical weathering and erosion, leaving more of their craters intact.
- Craters all over terrestrial objects in the solar system are evidence for a chaotic solar system, where objects were colliding more frequently than today.
- Frequent asteroid impacts must have made it difficult for life to survive and evolve.

6. Return to student ideas from the beginning of the Explore 2 phase about other factors that make Earth unique, such as: :
    - Maybe only the Earth has tectonic activity
    - Maybe only the Earth has oxygen

Summary

2. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

3. The results of this task can be used to make determinations about which students need more time to engage in sense-making about the role of water in geological process on Earth and their contribution to the changes in Earth's systems.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas: 1) **understanding how they are using the three dimensions, to make sense of a phenomenon** 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

How has the Rock Cycle Impacted the Stability of Craters on Earth?

Students use their understanding of **stability and change** to **apply scientific reasoning to assess the extent to which the data support claims** about **active geological processes interrupting the record of asteroid impacts** on Earth.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ The Rock Cycle	None	

Text-Based Task

1. Remind students about their questions regarding the Earth's atmosphere in the past, such as: *Are there other features of Earth that make it unique compared to the other planets? Do the other planets have tectonic activity?*

2. Tell students that rocks are constantly changing on Earth, partially due to water, but also because of other processes, in what is called the Rock Cycle.

3. Provide students with the handout, *The Rock Cycle*. Have students work in pairs to complete the task. For New York State Teachers: the Rock Cycle diagram comes from page 14 of the ESSRT.

Implementation Tip

For non New York State teachers, it may be better for your classes to use a more simplified version of the rock cycle. This version is beneficial because it allows students to connect geological processes to the presence of water and tectonic activity, but may be more detailed than your class needs.

4. Have students share out their findings.

Look & Listen For

- Water can be seen in the diagram in the processes of chemical weathering, erosion, and deposition
- Deposition creates sedimentary rocks, which are layered by age, with the oldest layers on the bottom
- These layers of sedimentary rock correlate with radioactive dating, which showed older samples in deeper layers of rocks
- The rock cycle demonstrates the constantly changing nature of the Earth's surface, which demonstrates why craters from 4 billion years ago may no longer exist on Earth's surface
- The diagram shows the connection between the rock cycle and tectonic plates, the movement of which could also damage craters
- Mercury, Mars, and the moon do not have active plate tectonics, which is another reason their craters have been stable over 4 billion years

Evaluate

How might asteroid collisions affect the probability of life evolving?

Students **develop an explanatory model** for how **asteroid collisions with Earth** have impacted **stability and change** of **Earth's systems** and the role they have played in the **evolution of life on Earth**, then use it to **make and defend an argument** about whether life or intelligent life exists somewhere outside Earth.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs ❑ Independent ❑ Table Groups	❑ Idea Carousel	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Revisiting the Performance Task: Stability of the Solar System 5E ❑ The Beginning of Life on Earth	None	❑ Chart paper ❑ markers ❑ sticky notes

Revisit the Performance Task

1. Tell students that we haven't yet connected this 5E to the idea of how life evolved on Earth and its possibility on other planets, which is our anchor phenomenon. Ask students to reflect on how they think a period of bombardment might have impacted the evolution of life.

2. Provide students with the handout *The Beginning of Life on Earth*. Have students work in pairs to date the sample using its uranium-238 content and the uranium-238 dating curve. Ask students to connect what they've learned about the stability and change of rocks on Earth to the strengths and limitations of

pinpointing when life first evolved using the fossil record.

3. Have students transition to the *Revisiting the Performance Task: Stability of the Solar System 5E* to construct an explanation in defense of a given claim that life evolved on Earth after the heavy late bombardment ended.

4. Have students independently respond to the prompts in their performance task research organizer for this Stability of the Solar System 5E.

5. Confer with students while they are working.

Conferring Prompts

Confer with students as they work to develop their explanations. Prompt students to return to the class wide scientific argument characteristics, posted in the room.
Suggested conferring questions:

- What evidence did you generate in this 5E sequence?
- Where did the evidence come from?
- How well does that evidence support the claim?
- What ideas or contradictory evidence weaken the claim?

6. Ask students to work in table groups to collaboratively revise their initial group explanations from the performance task launch. These should go onto new pieces of chart paper.
7. Facilitate student critique of one anothers' models through the Group Learning Routine **Idea Carousel**. Have students annotate other groups' models using post-its. Each post it should have a symbol and comment from each of the following categories:
    a. ✔ Write a check on sticky notes with comments about ideas represented in the model that resonate.
    b. ➕ Write a plus symbol on sticky notes with comments about ideas that should be added to the model.
    c. **?** Write a question mark on sticky notes with comments about ideas that you don't think are relevant to the model.
    d. **Δ** Write a delta symbol on sticky notes with comments about suggestions for how to clarify an idea or represent it more clearly.

Look & Listen For

While students are engaged in the Idea Carousel, listen for the following ideas. Where needed, discuss with groups what is coming up in their models, to ensure these points emerge in the classroom.

- The early solar system was very chaotic, with objects like young planets and asteroids colliding with each other frequently as the solar system became more stable.
- Based on radiometric dating of moon melt rock, the solar system was being bombarded by asteroids approximately 4 billion years ago
- The Earth was likely being bombarded at that time as well, although craters from that time did not survive because of the properties of water, which cause chemical and physical weathering, and because of tectonic activity, which together create the rock cycle and put the Earth in a constant state of change
- I don't think life could have evolved, definitely not intelligent life, during the Early solar system because life needs things to be pretty stable, otherwise species would just go extinct.
- Radiometric dating of the first fossil of life puts its appearance at 3.5 billion years ago, which aligns to the hypothesis that it could only appear on a stable planet
- If life had evolved earlier, though, we might not have the data due to the same processes that degraded impact craters
- For life to evolve on another planet, it would have to be in a stable solar system, where major collisions don't happen too often, so that systems on that planet don't change too much for life to survive

8. At the end of the Idea Carousel, it may be the case that some specific ideas have surfaced in some groups but not others. If that is the case, prompt those groups to share with the class. A share-out from every group, however, is not needed at this point.

9. Allow groups to use peer feedback and ideas shared by other groups to go back and revise their model.

Revisit the Driving Question Board

1. Use the **Driving Question Board Routine** to discuss which of the class's questions have been answered.

2. Have students identify which categories or questions they have not figured out yet. Prompt students to share out these questions, and document new questions that arise based on what they have been learning.

3. Add new questions to the Driving Question Board.

4. One question category still unanswered relates to questions about how volcanic eruptions could have killed almost all the species on Earth and what caused changes to the atmosphere.

5. Let students know that in our next investigations, they will have the opportunity to see how life evolved from that first fossil to now, and consider the unique set of circumstances that allowed it to happen.

Standards in Stability of the Solar System 5E

Performance Expectations

HS-ESS1-6 **Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.**
Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.
Assessment Boundary: None

In NYS, the phrase "Earth's oldest minerals" has been replaced with "Earth's rocks and minerals."

HS-ESS2-5 **Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.**
Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).
Assessment Boundary: None

In NYS the clarification statement has been edited as follows: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations could include stream transportation (erosion) and deposition using a stream table, infiltration and runoff by measuring permeability and porosity of different materials, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations could include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying out Investigations ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and	ESS1.C The History of Planet Earth ● Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early	Structure and Function ● The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. SEP3(2) Using Mathematics and Computational Thinking ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. SEP5(2) Constructing Explanations and Designing Solutions ● Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2) ● Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. SEP6(4)	rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. ESS1.C(2) ESS2.C The Roles of Water in Earth's Surface Processes ● The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit Sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. ESS2.C(1) PS1.C Nuclear Processes ● Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. PS1.C(2)	their components are shaped and used, and the molecular substructures of its various materials. CCC6(2) Stability and Change ● Much of science deals with constructing explanations of how things change and how they remain stable. CCC7(1)

Assessment Matrix

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Planning and Carrying out Investigations			*The Role of Water*		
Using Mathematics and Computational Thinking		*Early Solar System Investigation*			*Revisiting the Performance Task: Stability of the Solar System 5E*
Constructing Explanations and Designing Solutions	*Craters in the Solar System*	*Explaining the Craters in the Inner Solar System Summary Task*	*The Role of Water Summary Task*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*
ESS1.C The History of Planet Earth	*Craters in the Solar System*	*Explaining the Craters in the Inner Solar System Summary Task*	*The Role of Water*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*
ESS2.C The Roles of Water in Earth's Surface Processes			*The Role of Water*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*
PS1.C Nuclear Processes		*Early Solar System Investigation* *Explaining the Craters in the Inner Solar System Summary Task*			*Revisiting the Performance Task: Stability of the Solar System 5E*
Structure and Function			*The Role of Water*		
Stability and Change	*Craters in the Solar System*	*Early Solar System Investigation* *Explaining the Craters in the Inner Solar System Summary Task*	*The Role of Water* *The Role of Water Summary Task*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*

Common Core State Standards Connections

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Mathematics		MP4 MP5 MP7 MP1 MP2	MP2 MP5 MP6	MP1 MP7	MP1 MP2
ELA/Literacy		RST.9-10.3 RST.9-10.7 WHST.9-10.7 SL.9-10.4 WHST.9-10.8 SL.9-10.1 SL.9-10.2	RST.9-10.3 RST.9-10.7 WHST.9-10.8 SL.9-10.4 WHST.9-10.7 SL.9-10.1	RST.9-10.4 RST.9-10.5	WHST.9-10.4 WHST.9-10.5 WHST.9-10.8 WHST.9-10.10