ZOOMIN! Science

Exoplanets: Where Will We Find the Next Earth?

Lesson Question

Where will we find the next Earth?

Lesson Task

Students analyze planetary and stellar data from the Kepler mission to identify the exoplanet that they think is the most Earth-like and, therefore, the best candidate for further exploration. Students write their recommendations as memos to NASA and use data as evidence to support their choices.

Standards

Disciplinary Core Ideas

ESS 1.B Use observations of the sun, moon, and stars to describe patterns that can be predicted.

Science and Engineering Practices

Analyzing and Interpreting Data

- Analyze data using tools, technologies, and/or models in order to make valid and reliable scientific claims or determine an optimal solution.

Engaging in Argument from Evidence

- Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.

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OVERVIEW

Content Objectives

Students will understand how the transit method is used to detect Earth-sized exoplanets, what physical and orbital properties make a planet Earth-like, and around what types of stars we are most likely to find planets with the potential to sustain life. Key concepts include the following:

→ **Transit method.** Scientific instruments precisely measure the light coming from thousands of different stars, looking for "transits," periodic dips in the observed brightness of stars that indicate the presence of a planet. These dips in brightness also provide information about the planet's size and orbital period.

→ **Habitable zone.** Region around a star where a planet's surface temperature is "just right" for liquid water to flow and life to flourish.

→ **Sun-like stars.** Stars with temperatures and luminosities similar to those of Earth's sun.

Data Skill Objectives

Developing and Using Models

- Students will use a model of the stellar habitable zone to guide their analysis of planetary and stellar data and explore what they think are the most Earth-like planets.

Analyzing and Interpreting Data

- Students will connect table displays and visualizations of data (dot plots) to attributes of planets and their stars.
- Students will understand what a case represents, and that data can include both numbers and attributes, by mapping attributes of planets and their stars to a data set.

Instructional Sequence

Before you begin the lesson you should share a brief agenda with students:

→ **HOOK** — We'll start together, by thinking about how likely it is that there are other Earth-like planets in our galaxy.

→ **BACKGROUND** — We'll go over background information about the following:

- The Kepler Space Telescope and how it gathered data about exoplanets
- Where Earth-like planets are mostly likely to be found (i.e., in the habitable zones of stars
- How to use the Hertzsprung-Russell (H-R) diagram to understand the properties of stars

→ **DATA ORIENTATION** — We'll familiarize ourselves with Kepler data and practice using data analysis tools and techniques that will be useful in your investigation. You will learn how to narrow down a large data set by filtering out data you don't need to address the challenge, resulting in a smaller, more manageable amount of data to investigate further.

→ **INVESTIGATION** On your own, you'll analyze Kepler data to identify an Earth-like planet that you would recommend for further investigation in the search for life in the universe. You'll decide which characteristics of exoplanets and the stars they orbit are most important in determining how similar those exoplanets are to Earth, and filter the data based on these variables.

→ **WRITING** Finally, you'll write up your recommendation of which exoplanet you think is most Earth-like and therefore worth further investigation by astronomers, and use the data you've gathered to support your explanation of why that planet is the best choice.

Lesson Background for Teachers

Discovering thousands of planets beyond our solar system is a major milestone in human history, but the age-old question Are we alone? continues to be at the forefront of scientific exploration and students' curiosity about Earth's place in the universe. In this lesson, students get the opportunity to analyze real data from the Kepler Space Telescope to identify Earth-like planets orbiting other stars in our galaxy.

The Kepler Space Telescope, launched in 2009, was designed to scan a nearby region of the Milky Way galaxy in search of Earth-sized planets, particularly those in the habitable zones of stars where liquid water might exist on the surface of the planet. The overall goal was to determine the fraction of the hundreds of billions of stars in our galaxy that might have such planets and the properties of stars that have planetary systems. With only a few, narrow slices of our Milky Way galaxy so far surveyed, scientists now estimate that there is, on average, at least one planet around every star in the galaxy. That means there's something on the order of a trillion planets in our galaxy alone, many of them in Earth's size range.

The exoplanets in the Kepler data set were discovered using the transit method, which is looking for small dips in the brightness of stars due to planets passing in front of them (similar to an eclipse or a bug flying in front of a light bulb and temporarily dimming the light). Astronomers have detected exoplanets using five different methods, with the transit method being the most successful to date.

- **Radial velocity (watching for wobble):** Orbiting planets cause stars to wobble in space, changing the color of the light astronomers observe.
- **Transit (searching for shadows):** When a planet passes directly between its star and an observer, it dims the star's light by a measurable amount.
- **Direct imaging (taking pictures):** Astronomers can take pictures of exoplanets by removing the overwhelming glare of the stars they orbit.
- **Gravitational microlensing (light in a gravity lens):** Light from a distant star is bent and focused by gravity as a planet passes between the star and Earth
- **Astrometry (miniscule movements):** The orbit of a planet can cause a star to wobble around in space in relation to nearby stars in the sky.

For additional information on exoplanet detection, see NASA's website, 5 Ways to Find a Planet: https://exoplanets.nasa.gov/5-ways-to-find-a-planet/.

A planet's likelihood to support liquid water, and therefore life, depends on the star that the planet orbits. Therefore, the search for Earth-like planets begins with a search for stars with particular properties. One of the most useful tools in astronomy is the Hertzsprung–Russell diagram (H–R diagram), a scatter plot of stars' luminosity (intrinsic brightness) versus temperature (color/spectral type). These properties are what determine a star's habitable zone (distance from the star within which liquid water can potentially flow on a planet's surface).

Student Background Knowledge

Before starting this module, students should understand

- basic properties and dynamics of our solar system, including Kepler's laws of planetary motion.

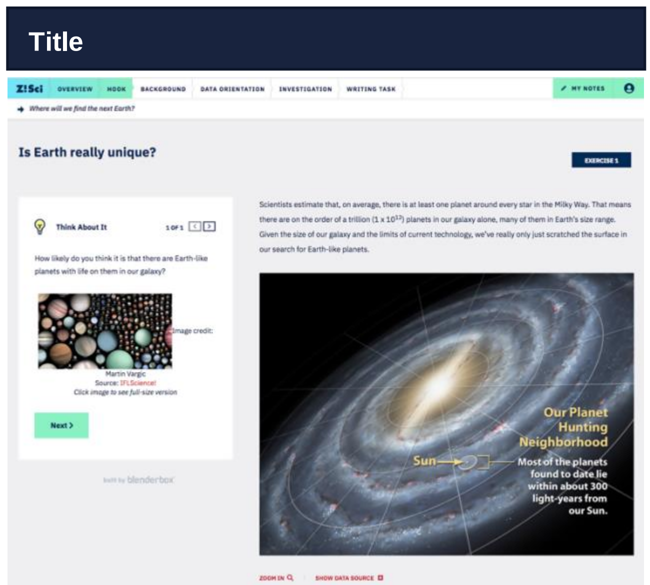
THE HOOK

[Estimated time: 15 minutes]

Is Earth really unique?

Purpose

Engage students in the lesson question: Where will we find the next Earth?



Big Ideas

- **Scale:** The universe is huge. Earth is small. Planets are plentiful.
- **Probability of finding another Earth** seems quite promising. Within our own solar system, 1 of 8 planets is an Earth-like planet known to have life. If the odds are similar within other planetary systems, there are potentially over 100 billion Earth-like planets just in our galaxy alone.

Facilitation Suggestions

- **Draw attention to the image** of "Our Planet Hunting Neighborhood" to help students get a feel for how small of an area of our galaxy (which itself is just a speck in the universe) has been explored for planets so far.
- **Pose the Think About It question** for discussion: How likely do you think it is that there are Earth-like planets with life on them in our galaxy?
- **As a follow-up**, have students consider how many planets in our own solar-system are Earth-like planets with life on them (1 out of 8: Earth).

TRANSITION TO BACKGROUND

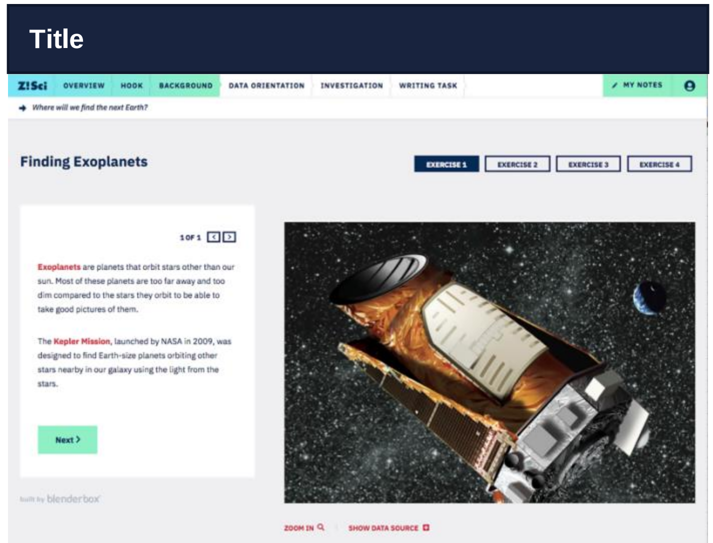
Tell students, "Now that we've decided that lots of Earth-like planets probably exist, we need to know something about how scientists decide which exoplanets could be Earth-like."

Background

[Estimate time: 30 minutes]

Show each background slide to the class, and have students actively read and discuss the content and questions posed as a basis for developing their knowledge of information that is important to their investigation.

Background 1: Finding Exoplanets



Purpose

Introduce students to what exoplanets are and what technology is used to find them.

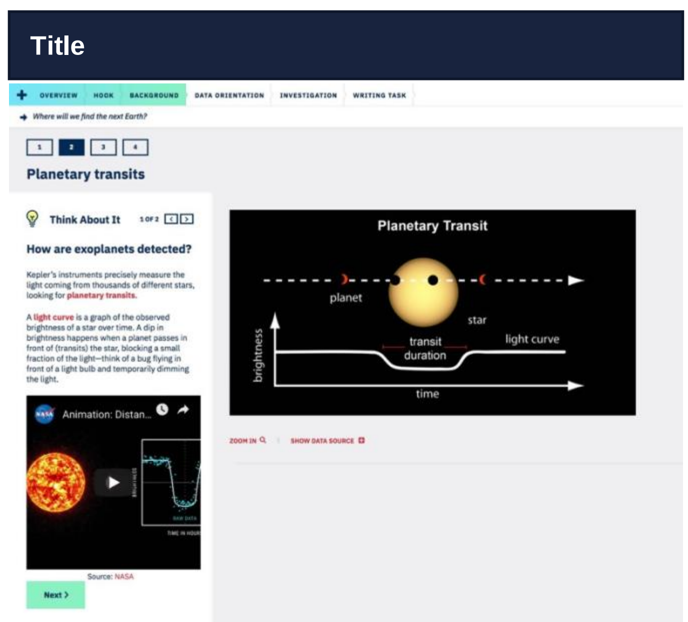
Big Ideas

- **Exoplanets** are too far away and too dim to observe from the ground or to photograph directly.
- **The Kepler Space Telescope** uses the light from stars to detect exoplanets.

Facilitation Suggestions

Review new vocabulary and point out the rollover feature for glossary terms.

Background 2: Planetary Transits



Purpose

Help students understand how exoplanets are detected using starlight and what information about planets can be determined from light curves (i.e., graphs of brightness over time).

Big Ideas

Finding Earth-sized exoplanets is extremely difficult. Direct observation or the imaging of exoplanets is nearly impossible because the planets are so small and dim compared to the stars they orbit. However, when a planet passes in front of a star, it blocks some of the starlight.

Astronomers look for tiny, periodic dips in the brightness of stars as evidence of planets orbiting those stars.

- **The depth** of the dip in a light curve provides information about the size of the planet: The greater the decrease in brightness, the larger the planet.

- **The periodicity** of the dips provides information about the length of the planet's orbit and helps confirm that the object in question is a planet orbiting the star and not a transient object passing through the line of sight: The longer the time between dips, the longer the orbit. Usually, at least three transits are needed to confirm the presence of a planet.

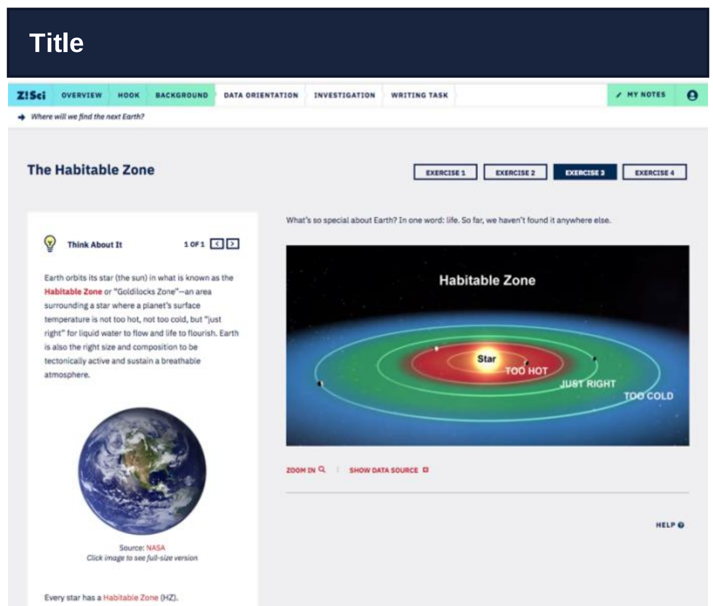
Facilitation Suggestions

- **Play the video**. Have students look at the light curve graphs and describe what they see.
- **If you have already covered Kepler's laws of planetary motion**, ask students to recall the relationship between orbital period and orbit semi-major axis.
- **Point out to students that the transit method relies on having the right viewing angle to detect the presence of a planet.** If the star and planet system are not being viewed face-on, the planet may go undetected.

Background 3: The Habitable Zone

Purpose

Highlight the importance of liquid water in the search for life in the universe. Introduce the term *habitable zone*, the area around a star where a planet's surface temperature is just right for liquid water to flow and life to flourish.



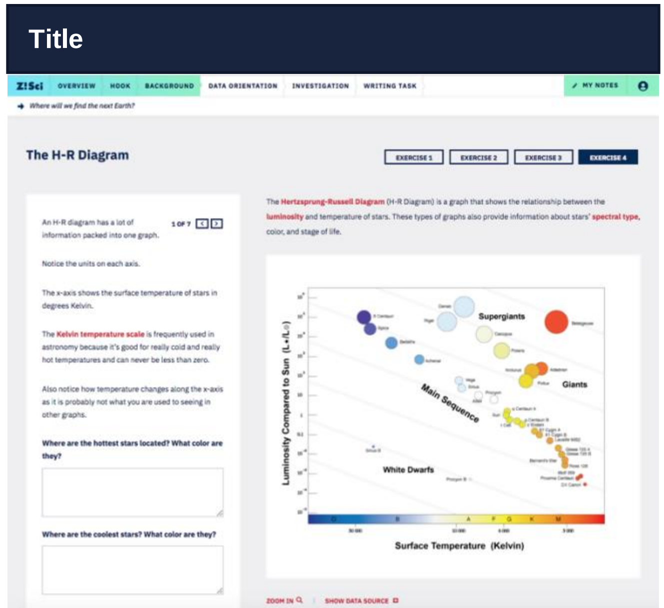
Big Ideas

- Life is what currently sets Earth apart from all other planets, and life as we know it depends on liquid water. So, the search for planets that might be capable of sustaining life is really a search for liquid water.
- To find planets that might have liquid water, we need to look in the habitable zones of stars.

Facilitation Suggestions

Discuss the habitable zone diagram and have students record their responses to the questions.

Background 4: The H-R Diagram



Purpose

Familiarize students with the H-R diagram, a graph that shows the relationship between the luminosity and the temperature of stars.

Big Ideas

- Planets are inextricably linked to the stars they orbit. The luminosity of a star is the primary factor in determining the location of a star's habitable zone.
- The location of a star on the H-R diagram lets you easily compare the star to the sun. *To find planets that are most like Earth, our best bet is to look at stars that are most like our sun.*

Facilitation Suggestions

The H-R diagram contains a lot of information. **Call students' attention to the axis labels, units, and scale.** Of particular note:

- The temperature decreases from left to right along the x-axis.
- The temperature is measured in Kelvin.
- The values along the y-axis are unit-less ratios.
- The luminosity of the Sun is used as the standard for comparison.

This background section also introduces a lot of vocabulary that may be unfamiliar to students. **You might consider using a Think-Pair-Share** approach to give students ample opportunity to study the diagram and answer the questions on their own with a partner before discussing each section as a whole class.

TRANSITION TO DATA ORIENTATION

Explain to students that the Kepler mission gathered a great deal of data about exoplanets, and that they will be learning techniques for working with and analyzing this data in the Data Orientation section.

DATA ORIENTATION

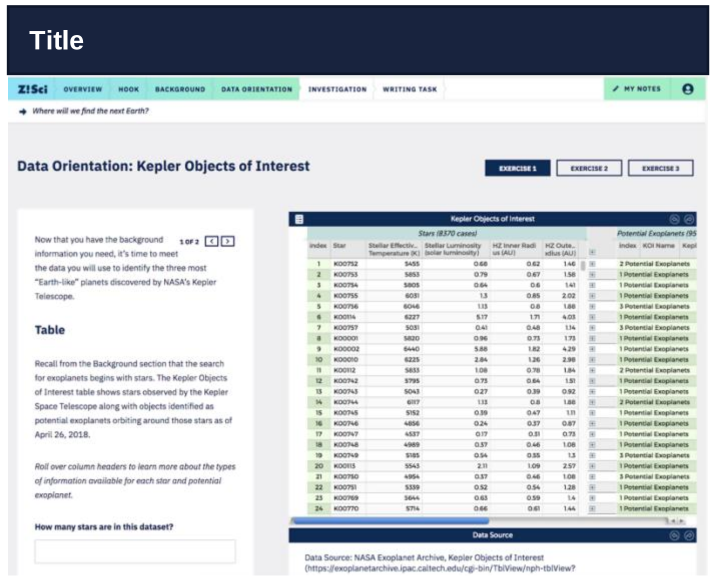
Estimated Time: 30 minutes

We recommend you continue to show these slides to the class and guide students as they practice manipulating the data. As students complete the three exercises, allow them to explore each data visualization, show them how to construct a graph, and discuss how filtering data helps answer the lesson question.

Data Orientation 1: Kepler Objects of Interest

Purpose

Familiarize students with the Kepler Objects of Interest data set and the CODAP tool.



Big Ideas

- As of the time this data set was compiled, the Kepler Space Telescope had identified 9,564 objects around 8,370 stars as potential exoplanets.
- This is a big data set!

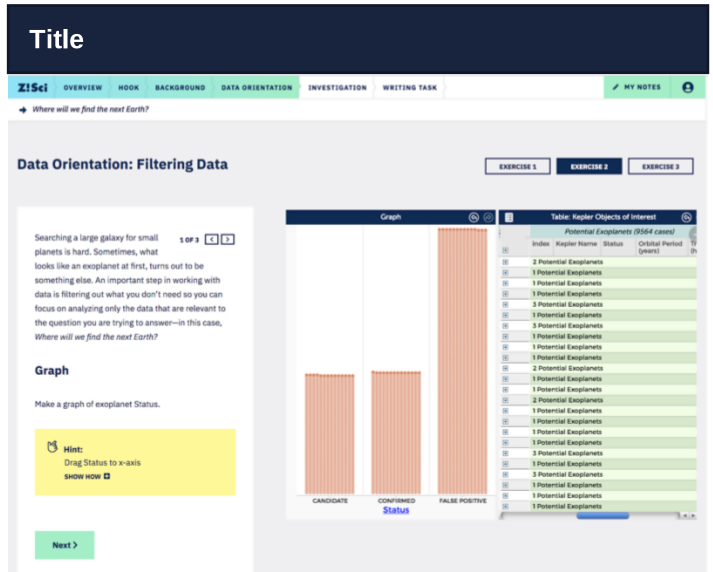
Facilitation Suggestions

- **Give students time to explore the data set.** Encourage them to roll over column headers in the table to learn more about what data are available for both stars and planets.
- **Ask students what it means that there are more planets than stars.** (Some stars have multiple planets, much like our solar system.)
- **Remind students that they can use the navigation links** to go back to the Background section or Glossary at any time.
- **Use the discussion questions to remind students of the lesson question,** *Where will we find the next Earth?,* and to get students thinking about narrowing down a data set to focus on only what they will need to address their challenge.

Data Orientation 2: Filtering Data

Purpose

Introduce students to the idea of filtering data. Teach students how to make a graph using CODAP.



Big Ideas

- An important step in working with data is filtering out what you don't need so you can focus on analyzing only the data that are relevant to the question you are trying to answer—in this case, *Where will we find the next Earth?*
- These are the same data and this is the same kind of filtering process professional astronomers use to winnow down a large data set to a more manageable or relevant subset to explore in more detail.

Facilitation Suggestions

- Point out **the connections between the table and graph.** Click on points on the graph to see corresponding data in the table. Click on rows in the table to see corresponding data points on the graph.
- Demonstrate **the "SHOW HOW" animations.** Before moving on, confirm that all students came up with the same number of confirmed exoplanets (2,297).
- Engage **students in a discussion around the question**, *How does filtering the data help with your task of identifying Earth-like exoplanets?* Listen to students to determine if they understand that filtering the data helps narrow down the options to a more manageable number of objects to study in detail.
- As a follow-up, **ask students to suggest other ways they might filter the data** to continue narrowing down the options.

Data Orientation 3: Confirmed Exoplanets

Purpose

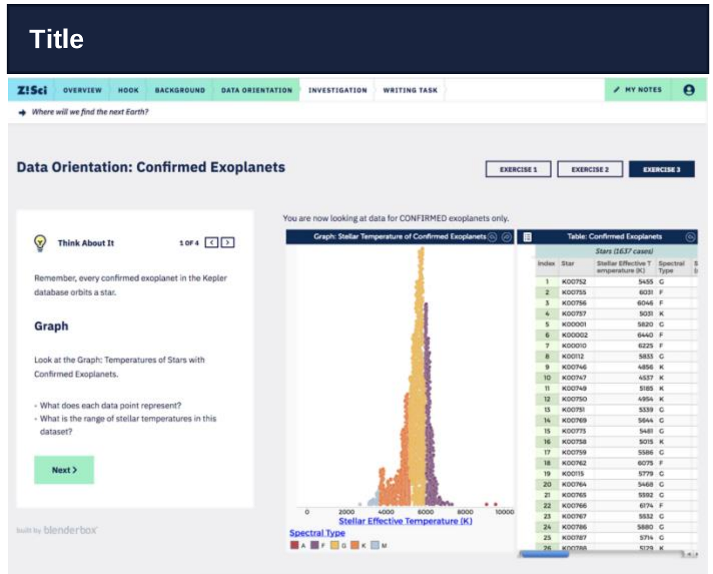
Teach students how to use CODAP tools and features to analyze and interpret data.

Big Ideas

Filtering the data set to show only confirmed exoplanets decreases the number of data points so students can begin to look for meaningful patterns that will help them with their overall task of identifying the most Earth-like exoplanet.

Facilitation Suggestions

Make sure students are aware that they are now looking at data associated with CONFIRMED exoplanets only (a smaller data set than the one they were working with in the previous Data Orientation section).



TRANSITION TO INVESTIGATION

Now that students know how to work with CODAP, they will continue to work with the data on their own to answer the question, *Where will we find the next Earth?*

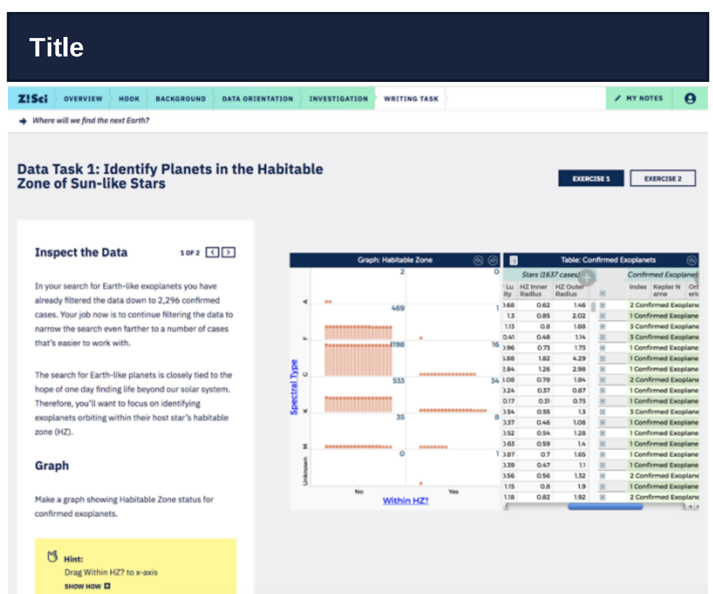
INVESTIGATION: Find Earth-Like Planets

Estimated Time: 60 minutes

Data Task 1: IDENTIFY PLANETS IN THE HABITABLE ZONE OF SUN-LIKE STARS

Purpose

Students continue filtering the data to isolate exoplanets orbiting within their host star's habitable zone (HZ).



Big Ideas

- Earth-like planets will be found within the HZ of their host star, so data for other planets and stars can be ignored.
- Graphs are a useful tool for sorting and isolating data.

Facilitation Suggestions

- Remind **students that they can revisit the Data Orientation section** if they need a refresher on how to use the CODAP tools.
- If students make mistakes with their graphs and need to start over, or they just want to try something new, **point out the undo button at the top of the graph and the RESET GRAPH button at the bottom right corner of the browser window.**

Undo:

Start Over:

At the end of Data Task 1, students should end up with just 16 exoplanets that meet all criteria (orbiting within the HZ of a G-type star). Before moving on to Data Task 2, consider having students pause for a brief discussion of what they have done so far and what they have found to be surprising, interesting, or challenging.

Data Task 2: Identify Earth-Sized Planets

Purpose

Students isolate a subset of exoplanets that are Earth-sized (R = 0.5–2.0 times the radius of Earth) and orbiting within the HZ of their host star) and decide which three planets are the most Earth-like based on the data available to them.

Title

Big Ideas

- The Kepler mission confirmed over 1,000 Earth-sized exoplanets, *but size alone does not make an exoplanet Earth-like*. Only 23 of the Earth-sized planets orbit within their host star's HZ, and only 2 of those orbit G-type stars.
- No exoplanets in this data set are exactly like Earth. Students must weigh all the evidence and decide which factors they think are most important in making their decisions.

Facilitation Suggestions

Check in with students periodically to make sure they are able to successfully filter the data. When students get to the final steps, they will have to do some critical thinking about the data to arrive at a decision about which three planets are most Earth-like. The exoplanets that are closest in size to Earth are not orbiting G-type stars (like Earth's sun).

Without having them reveal their final choices, engage students in a discussion around what criteria they are using to decide which planets are most Earth-like.

- Which do they feel is more important—size or spectral type of the star?
- What other data might they look at for the planets they are considering to help them make their final decisions (e.g., orbital period or semi-major axis)?

TRANSITION TO WRITING

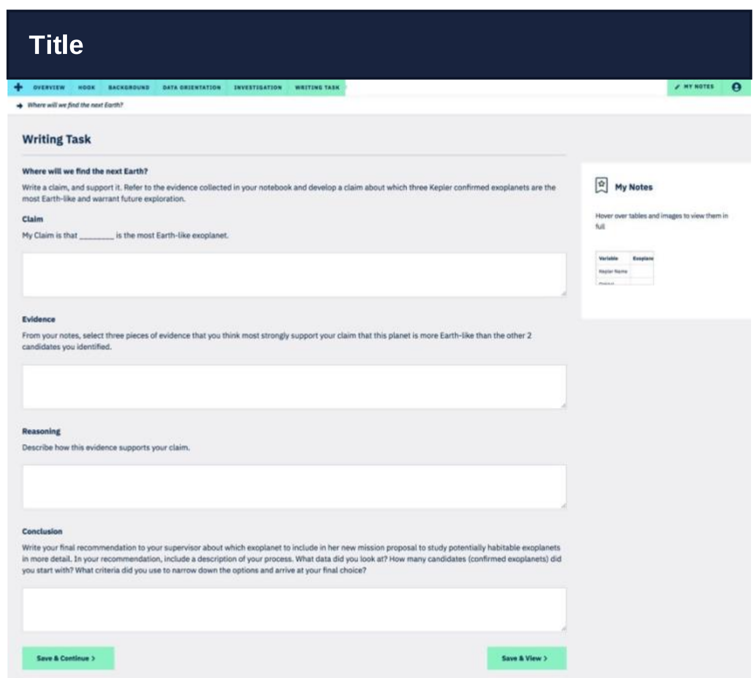
Explain that students will next review their notes and complete a structured writing exercise to present their answers to the lesson question.

WRITING TASK: Where Will We Find the Next Earth

Estimated Time: 30 minutes

Purpose

Students synthesize what they have learned to address the lesson question.



Big Ideas

- Students can effectively communicate their answer to the lesson question by making an evidence-based claim about which exoplanet discovered by the Kepler mission is the most Earth-like.
- Students use data as evidence and provide sound reasoning about how the evidence they chose supports their claim.
- Students are able to pull together all pieces of the lesson to write a recommendation to their fictitious internship supervisor about which planet to include in the proposal for a new mission to study potentially habitable exoplanets in more detail.

Facilitation Suggestions

- **Encourage students to review their notes from the entire lesson and to revisit the Background section if they need a refresher** about what factors are most important in the search for Earth-like planets beyond our solar system.
- **Remind students that there is no correct answer to this challenge**. The important part is to make a strong case for their choices using the data as evidence.

Assessment

Look for the following when evaluating students' writing tasks.

CLAIM

Students should provide the Kepler name of their choice in the format "Kepler-#" plus the lower-case letter that identifies the planet.

Example:

My claim is that Kepler-452 b is the most Earth-like exoplanet.

EVIDENCE

Students should provide three pieces of evidence to support their claim that the exoplanet they chose is more Earth-like than the other two candidates they identified.

Evidence could include:

- Planet size (radius), which should be somewhere between 0.5 and 2 times the radius of Earth.
  - Spectral type, temperature, or luminosity of the host star:
  - The spectral type should be K, G, or F.
  - Temperature should be relatively close to 5,778 K (the temperature of Earth's sun).
  - The luminosity should be close to 1 (the luminosity of Earth's sun).
- Planet orbits within its star's HZ.
- Orbital period and/or semi-major axis are similar to that of Earth (1 year/1 Astronomical Unit)

Example:

My three pieces of evidence to support my claim are (1) Kepler-452 b has a radius of 1.09 Earth radii, (2) an orbital period of 1.05 years, and (3) has an orbit with a semi-ajor axis of 0.99 AU that is within the habitable zone of a G type (sun-like) star.

REASONING

Students' reasoning should describe how their evidence supports their claim. Look for comparative language that shows students made their choices by comparing the exoplanets to Earth and one another.

Example:

My evidence supports my rebuttal because Kepler-452 b meets all the criteria for being an Earth-like planet and meets them more closely than the other two candidates I identified (Kepler-69 c and Kepler-62 f). An Earth-like exoplanet has to have a radius of 0.5-2 times the radius of Earth and orbit within the HZ of a sun-like star. Kepler-452 b has a radius of 1.09 Earth radii, which is closer to the exact size of Earth than Kepler-69 c and Kepler-62 f, which have radii of 1.73 and 1.43 Earth radii. Both Kepler-452 b and Kepler-69 c orbit around G-type stars, just like the Earth does. All three exoplanets orbit within their star's HZ, but Kepler-452 b has an orbital period of 1.05 years and a semi-major axis of 0.99, which are very similar to those of Earth (1 year, 1 AU). Both of the other 2 candidates have shorter orbital periods, which means that they orbit closer to their stars than Kepler-452 b does.

CONCLUSION

Students' final recommendations to their NASA internship supervisor should be written in clear, complete sentences and include specific data values and units.

Example:

My NASA supervisor should include Kepler-452 b in her proposal because it has physical and orbital characteristics that are nearly identical to those of Earth and therefore has a higher probability of being able to support life than other planets. While other planets are also promising, the evidence most strongly supports Kepler-452 b as the strongest candidate. This exoplanet orbits within the HZ of a star that is the same spectral type as our sun (G), at a distance that is nearly identical to Earth's orbit (0.99 AU).