Celestial Jukebox

Grades: 9-12  Prep Time: ~10 min  Lesson Time: 110-115 minutes

WHAT STUDENTS DO: Use a model to derive Kepler’s Third Law.

Students will use the pattern of sound to observe transits. They will derive Kepler’s Third Law from the data they collect within our solar system. Then they will apply Kepler’s Third Law to extrasolar systems and the search for exoplanets while collecting rare coins along the way.

NRC FRAMEWORK/NGSS CORE & COMPONENT QUESTIONS

WHAT IS THE UNIVERSE, AND WHAT IS EARTH’S PLACE IN IT?
NGSS Core Question: ESS1: Earth’s Place in the Universe

What are the predictable patterns caused by Earth’s movement in the solar system?
NGSS ESS1.B: Earth and the Solar System

INSTRUCTIONAL OBJECTIVES (IO)

Students will be able to

IO1: Develop and use a model of the solar system to derive and explain Kepler’s 3rd Law, then apply the equation to search for exoplanets in orbit around their stars.
1.0 Materials

Required Materials:

Please Supply:

- Computer or Laptop – 1 per student
- Supported Browsers: Chrome; Edge; Firefox; Safari

Please Print:

From Student Guide

(A) Transit Examples – 1 per small group
(B) Interpreting Light Curves Recording Sheet – 1 per student
(C) Kepler’s Third Law Evaluation – 1 per student

Optional Materials:

From Teacher Guide

(B) Interpreting Light Curves (2 of 2) Recording Sheet (KEY)
(C) Kepler’s Third Law Evaluation (Key)

From Alignment Document

(N) Celestial Jukebox Alignment Rubrics
2.0 Lesson Timeline

**Celestial Jukebox Lesson Timeline:**

**Time:**
- 110 - 115 minutes

**Materials:**
- Student Guide pages

5-E Inquiry Process:
- The arrow color represents the 5-E step students will be primarily engaging in for that class session

Day 1
- (~15-20 min)
  - Engage
    - *NASA Eyes on Exoplanets*
    - Q&A

Day 1-2
- (~ 45 min)
  - Explore Celestial Jukebox Learning Experience

Day 1-2
- (~ 5 min)
  - Explain
    - During Celestial Jukebox Experience
    - Follow up Q&A

Day 2-3
- (~30 min)
  - Elaborate
    - Transits Example
    - Light Curve Discussion
    - Interpreting Light Curves

Day 3
- (~15 min)
  - Evaluate
    - Q&A
    - Kepler’s Third Law Evaluation

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### 3.0 Vocabulary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>astronomical unit</td>
<td>a unit of measurement that represents the average distance between Earth and the Sun</td>
</tr>
<tr>
<td>distance</td>
<td>the length of a straight line between two points</td>
</tr>
<tr>
<td>exoplanet</td>
<td>a planet that orbits a star outside the solar system</td>
</tr>
<tr>
<td>exponent</td>
<td>a number representing how many times a value should be multiplied by itself</td>
</tr>
<tr>
<td>extrasolar systems</td>
<td>solar systems with exoplanets in orbit around their stars</td>
</tr>
<tr>
<td>frequency</td>
<td>how often an event occurs</td>
</tr>
<tr>
<td>function</td>
<td>a relationship or expression involving one or more variables</td>
</tr>
<tr>
<td>model</td>
<td>a simulation that helps explain natural and human-made systems and shows possible flaws</td>
</tr>
<tr>
<td>observations</td>
<td>specific details recorded to describe an object or phenomenon</td>
</tr>
<tr>
<td>orbital period</td>
<td>the amount of time it takes for a planet or exoplanet to make one full revolution around the Sun or a star, respectively</td>
</tr>
<tr>
<td>planet</td>
<td>a sphere moving in orbit around the Sun</td>
</tr>
<tr>
<td>prediction</td>
<td>a declaration or statement of what will happen based on reason and knowledge</td>
</tr>
<tr>
<td>proportional</td>
<td>when a variable is related to another quantity; such as a ratio</td>
</tr>
<tr>
<td>scale</td>
<td>a comparative relation between objects such as size or distance</td>
</tr>
<tr>
<td>speed</td>
<td>distance traveled over time</td>
</tr>
<tr>
<td>star mass</td>
<td>the amount of matter contained within a star</td>
</tr>
<tr>
<td>transit</td>
<td>the passage of a planet, exoplanet, moon, or asteroid across the face or disk of a star or other planetary body</td>
</tr>
</tbody>
</table>
4.0 Procedure

PRIOR KNOWLEDGE & SKILLS

A. Arrangement of the Solar System
B. Planet Names
C. Square Roots
D. Cube Roots
E. Solving Polynomials

PREPARATION

A. Visit https://infiniscope.org/lesson/celestial-jukebox/ for access to the digital learning experience and additional resources.

B. PRINT THE FOLLOWING:

- (A) Transit Examples – 1 per small group
- (B) Interpreting Light Curves Recording Sheet – 1 per student
- (C) Kepler’s Third Law Evaluation – 1 per student

C. DOWNLOAD:

- NASA Eyes on Exoplanets App (https://eyes.nasa.gov/eyes-on-exoplanets.html)

STEP 1: ENGAGE (~15 - 20 min)

Introduce Exoplanets and Elicit Prior Knowledge of Discovery

A. Have students open the NASA Eyes on Exoplanets app and allow them 10 - 15 minutes to explore depending on their level of engagement.

B. Facilitate Q&A with students and record their responses to revisit:

1. *How do scientists find these exoplanets?*
   i. Responses will vary. Students may have no idea or refer to powerful telescopes.

2. *Once they’ve found these exoplanets, how do they know the distances these exoplanets are from the star they orbit?*
   i. Responses will vary. Students may have no idea or refer to scientists don’t know.

C. Say “These are all interesting ideas on how scientists discover and learn about these exoplanets. Let’s find out!” Explain they will be using a digital simulation to explore the discovery methods of exoplanets.
STEP 2: EXPLORE (~ 45 min)
Celestial Jukebox Exploratory Activity

A. Hand out or assign computers and ask students to access the Celestial Jukebox digital learning experience at https://infiniscope.org/ and choose “Explore” to launch the experience.

 Teacher Tip: If students seem to be stuck in the activity, it isn't responding in a way that seems correct, or if an error occurs, click the three horizontal lines in the upper right corner and choose “Restart Lesson” from the dropdown list. “Restart Lesson” will clear all of their progress and bring them back to the start screen. Hitting the browser’s “Refresh” or “Back” button will not restart the activity. If restarting still does not correct the error, please submit an error report using the “Report an Issue” button.

 Teacher Tip: If you would like to analyze student interactions in this activity, you can sign up to join the Infiniscope Teaching Network (https://infiniscope.org/join/) and enroll your group into the activity. By enrolling, you will gain access to the analytics of the activity by student to see how they progressed through the activity. You also have the ability to adopt the activity and adapt it to the specific needs of your classroom, school, or community.

 Time Management Tip: Should you run out of time for students to complete this activity there are a couple of options.

• Option 1: If students are enrolled in the class through the Infiniscope Teaching Network, they can log in at home or at school at another time and pick up where they left off.

• Option 2: If students are NOT enrolled in the class through the Infiniscope Teaching Network, they can restart the activity at home and complete at their own pace.

STEP 3: EXPLAIN (~ 5 min)
Check for Understanding

A. Questions are embedded within the experience to verify students are connecting their activities to key concepts. If you have time at the conclusion of their exploration, you can ask these questions again to affirm their understanding. Purple text indicates the correct response.

a. The farther a planet is from a star the [ Farther apart ] the tones occur.

b. In summary, Kepler's third law states that the cube of a planet’s [ Distance ] is proportional to the square of its [ Period ]. This means that planets closer to the Sun will have a [ Shorter ] orbital period than planets farther from the Sun.

 Misconception Alert: It is important to point out to students that a transit actually does not make a sound.
STEP 4: ELABORATE (~ 30 min)
Apply Kepler’s Third Law

⚠️ Misconception Alert: Students often have clear misconceptions regarding the appearance of these exoplanets. Publications typically show images of exoplanets when they have been discovered. It’s important to inform students that these images are nothing more than artistic renderings. Some renderings are based on small pieces of scientific info, but astronomers have never directly observed a planet around another star.

A. What is the indicator for a transit if it isn’t a sound. Use the images provided on (A) Transit Examples. Ask students to brainstorm what is measured during a transit if it isn’t actually a sound.

B. Discuss ideas students have brainstormed. Guide the conversation toward light and light curves. Telescopes, like Kepler, are sensitive enough to measure differences in brightness of a star. The data collected during observation reveals a pattern when plotted. These graphs are called light curves. These light curves are similar to the ones observed in the Celestial Jukebox experience. The following video demonstrates the light curve concept: (https://www.youtube.com/watch?v=Rrs1ZaWDW8)

C. Hand out (B) Interpreting Light Curves Recording Sheet for students to continue applying concepts from Celestial Jukebox to the search for exoplanets using light curves.

STEP 5: EVALUATE (~ 15 min)
Kepler’s Third Law Evaluation

A. Revisit the questions asked prior to exploration.

B. Ask students:

   a. How do astronomers find these exoplanets? Responses should discuss transits and dips in light (light curves).

   b. Once they’ve found these exoplanets, how do they know the distances these exoplanets are from the star they orbit? Responses should discuss using transits to plug in values for Kepler’s third law and solve for distance.

C. Hand out (C) Kepler’s Third Law Evaluation to assess student understanding of the mathematical concepts.
5.0 Evaluation/Assessment

Use the *(N)* Celestial Jukebox Alignment Rubric as a formative assessment, allowing students to improve their work and learn from mistakes during class. The rubric evaluates the activities using the Learning Outcomes identified in the Alignment Documents for the activity.

6.0 Extensions

1. Revisit the NASA *Eyes on Exoplanets* visualization.
2. Explore the NASA *Exoplanet Exploration* page.
4. Search for planets using *Planet Hunters*.
(A) Transit Examples

**Instructions:** What is the indicator for a transit if it isn't a sound? Use the images provided as a clue to brainstorm what is measured during a transit if it isn't actually a sound.
Instructions: Use the graphs below to answer the questions.

Name: _______________________________
CELESTIAL JUKEBOX
(b) Interpreting Light Curves (2 of 2) Recording Sheet

1. Which exoplanet has the shortest orbital period? A B C
   How do you know?
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________

2. Which exoplanet is the farthest from the star? A B C
   How do you know?
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________

3. What would be a possible reason for the difference in light intensity between graphs A, B, and C?
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________
(C) Kepler’s Third Law Evaluation (1 of 2)

Name: ______________________________________

Instructions: Based on what you discovered in Celestial Jukebox, answer the questions below.

1. What is the correct distance for a planet with a period of four years?
   a. 2 AU   b. 2.5 AU   c. 4 AU   d. 8 AU

2. Write the equation that correctly represents this graphical relationship.
3. What are all the ways you could explain to someone the relationship between the speed of a planet and its distance from the Sun? Explain each using details from *Celestial Jukebox*.

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CELESTIAL JUKEBOX

Teacher Guide

(B) Interpreting Light Curves (2 of 2) Recording Sheet (KEY)

1. Which exoplanet has the shortest orbital period?
   - A
   - B
   - C

   How do you know? *The dips on the light curve occur more often (frequently).*

2. Which exoplanet is the farthest from the star?
   - A
   - B
   - C

   How do you know? *The dips on the light curve occur less often (not as frequent).*

3. What would be a possible reason for the difference in light intensity between graphs A, B, and C?
   - The difference is related to the size of the transiting exoplanet. Larger exoplanets will create larger dips in light, while smaller planets will create smaller dips.

   *Students may or may not intuit this concept.*
Instructions: Based on what you discovered in Celestial Jukebox, answer the questions below.

1. What is the correct distance for a planet with a period of four years?
   a. 2 AU  
   b. 2.5 AU  
   c. 4 AU  
   d. 8 AU
   - Answer: b. 2.5 AU

2. Write the equation that correctly represents this graphical relationship.
   \[ p^2 = d^3 \text{ or Period squared equals distance cubed} \]
1. What are all the ways you could explain to someone the relationship between the speed of a planet and its distance from the Sun? Explain each using details from *Celestial Jukebox*.

*There are a variety of ways students could respond to this question. Responses could be, but are not limited to the following:*

- **Mathematical descriptions (equation):** a discussion of \( p^2 = d^3 \) or Period squared equals distance cubed using examples and citing the overall result. Equation created predictability of an exoplanet’s location in orbit.

- **Graphical (slope or curve):** a discussion on the slope 3/2 generating a curve that can be used to accurately predict the location of an exoplanet in orbit.

- **Conceptual (general discussion of distance and speed):** a discussion of the farther away an exoplanet is from its star, the longer it takes to orbit and therefore fewer transits, etc.