TEACHER ANSWER KEY

Exploring Exoplanets with Real Data

Model answers for the 90-minute high-school activity

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Teacher guidance Use this key flexibly. The exoplanet.eu catalogue is regularly updated, so exact counts, peaks and extreme values can shift slightly from one class session to another. Reward correct scientific reasoning more than exact numbers.

What this answer key includes

- Sample answers to every question in the worksheet
- Approximate values where the live catalogue may vary
- Short teacher notes on what to accept from students

Recommended correction strategy

- Look first for trend recognition.
- Accept equivalent wording if it is scientifically sound.
- Use the notes in the right column for common variations.
- Encourage students to connect patterns with detection bias.

Data sources Student worksheet based on exoplanet.eu plotting tools and the Exo4Edu educational framework.

Answer Key

Use together with the student worksheet. Sample wording can be shortened during classroom correction.

PART A — The discovery boom

Question / prompt	Suggested answer	Teacher note
During which periods does the number of discoveries increase most strongly?	A good answer identifies at least two major acceleration phases: an early rise after the first confirmed exoplanet discoveries in the mid-1990s, a very strong increase in the Kepler era (roughly 2009–2014), and another important rise in the late 2010s / 2020s with large survey pipelines and TESS-era discoveries.	Exact years may vary slightly with the live database. Accept any answer that identifies clear growth phases rather than isolated single years.
Suggest two reasons for these increases.	Expected reasons include: (1) better instruments and radial-velocity precision; (2) dedicated space missions and surveys such as CoRoT, Kepler or TESS; (3) improved data-processing pipelines and follow-up confirmation; (4) more telescopes and larger observing programs.	Students do not need to name all missions. Two well-explained reasons are enough.
Why does the histogram not rise smoothly from one year to the next?	Because discoveries are not published continuously one by one. They often appear in batches after survey campaigns, data reprocessing, candidate validation and publication delays. Different techniques and projects also contribute at different times.	Accept "discoveries come in groups / campaigns" if the idea is clear.

Model conclusion for Part A

- The discovery rate increased dramatically when dedicated exoplanet surveys and space missions began to deliver large, homogeneous datasets.
- The curve is irregular because the catalogue grows through campaigns, confirmations and publication waves rather than in a perfectly continuous way.

PART B — Histograms: mass, orbital distance and eccentricity

Question / prompt	Suggested answer	Teacher note
Observation table — Mass histogram	Main pattern: the database spans several orders of magnitude, from very small planets up to many Jupiter masses. When students switch to Earth-mass units and a log scale, the spread becomes easier to read and a transition around a few tens of Earth masses often becomes more visible, separating Neptune-like planets	Suggested label in the worksheet table: "both" (real astrophysics + detection bias).

	from giant planets.	
Observation table — Semi-major axis histogram	Main pattern: many detected planets are very close to their star, with a strong concentration at small orbital distances and a long tail toward larger semi-major axes.	Suggested label: “both”, with detection bias especially important.
Observation table — Eccentricity histogram	Main pattern: nearly circular and moderately eccentric orbits are common, whereas extremely elongated orbits are rarer.	Suggested label: “mostly physics, but some bias also matters”; “both” is acceptable.
Mass histogram: approximate minimum and maximum masses visible? What changes on a log scale?	Reasonable classroom answer: the mass range runs from below 1 Earth mass to many Jupiter masses. In Earth units, students should notice values from fractions of an Earth mass to several thousand Earth masses. If the full “all objects” preset is used, the upper end can approach the catalogue limit near 60 Jupiter masses. On a log scale, the distribution is easier to read and different populations are easier to distinguish.	Accept approximate numbers. The key point is “huge range over many powers of ten”.
Semi-major axis histogram: where are most detected planets relative to their star?	Most detected planets are relatively close to their star, often inside Earth’s orbit and many even inside Mercury’s orbit. There is a long tail to larger distances, but the inner region is much more populated in many surveys.	A comparison with Mercury (0.39 AU), Earth (1 AU) and Jupiter (5.2 AU) should show that many detected planets lie well inside 1 AU.
Why are close-in planets often overrepresented?	Because they are easier to detect. Transits are more probable for short orbital distances and happen more often during one observing campaign. Radial-velocity signals are also larger and repeat more quickly for close-in planets, especially massive ones.	This is the central detection-bias idea of the worksheet.
Eccentricity histogram: are nearly circular or highly elongated orbits more common? Compare with the Solar System.	Several exoplanets have an eccentricity of exactly zero. These are planets for which we have no information on the shape of the orbit, which we therefore assume to be circular (e=0). It is noted that the distribution of eccentricities is decreasing, but there are still many planets with highly eccentric orbits. Compared to the planets of the Solar System, we see that many exoplanets have much more eccentric orbits than the planets of the Sun: Mercury: 0.2 - Venus: 0.007 - Earth: 0.02 - Mars: 0.09 - Jupiter: 0.05 - Saturn: 0.05 - Uranus: 0.05 - Neptune: 0.004	Accept “our Solar System is more orderly / less eccentric overall”.

Teacher emphasis Students should explicitly connect the close-in peak to selection effects: a catalogue is never a perfectly unbiased photograph of nature.

PART C — Mass–radius diagram: what are planets made of?

Question / prompt	Suggested answer	Teacher note
Identify at least three broad families of planets or objects.	Typical families visible on the mass–radius diagram are: (1) rocky planets / super-Earths, (2) sub-Neptunes / Neptunes, and (3) gas giants. Depending on the current dataset, students may also mention inflated giants or very massive objects approaching the brown-dwarf regime.	Accept equivalent labels if the grouping is physically sensible.
Do planets with Earth-like radius all have the same mass? What does this imply?	No. Planets with similar radii can have different masses, which means they have different densities. This points to different internal compositions: some are rock/iron rich, while others are less dense because they contain more volatiles or gas.	The key concept is density = composition clue.
Where would dense rocky planets such as Earth or Mercury lie on this plot?	Because the x-axis is mass and the y-axis is radius, dense rocky planets lie in the small-radius region but with comparatively higher mass for their size. In practice, they sit to the right of puffier low-density planets of similar radius, or below low-density planets of similar mass.	Students often confuse “above” and “right”; accept either if they justify it in terms of density.
Choose one small planet and one giant planet and compare them in one sentence.	Model sentence: “A small rocky planet has a radius of only a few Earth radii or less and a relatively high density, whereas a giant planet is much larger in radius and is dominated by a thick hydrogen-helium envelope.”	Any clear, physically correct comparison is acceptable.

One-sentence summary for Part C

- The mass–radius diagram shows that exoplanets do not form a single simple sequence: planets of similar size can have very different masses and therefore very different densities and compositions.

PART D — Kepler’s third law in real data

Question / prompt	Suggested answer	Teacher note
What overall trend appears between period and semi-major axis?	The general trend is positive: planets with longer orbital periods are usually farther from their star, so the semi-major axis increases as the period increases.	Students should identify a clear increasing relation.
Why does a log–log plot help you see this relation?	A log–log plot compresses a very wide numerical range and turns a power-law relation into something close to a straight line. That makes the Kepler trend much easier	This directly connects to the math note in the

	to recognize.	student worksheet.
Do planets in a single system follow the same trend?	Yes. Within one planetary system, the planets generally line up along the same increasing period–distance relation because they orbit the same star, so Kepler's third law applies with the same central mass. The relation is usually cleaner in one system than in the full catalogue.	Accept mention of small scatter and common host-star mass.
Optional challenge: if the period is multiplied by 10, what happens to the semi-major axis?	For planets orbiting the same star, a ∝ P^(2/3). So if the period is multiplied by 10, the semi-major axis is multiplied by 10^(2/3) ≈ 4.6. This is consistent with the trend seen in a log–log plot.	A rounded value between about 4.5 and 4.7 is fine.

Model conclusion for Part D

- The period–distance plot is a clear example of a physical law emerging from real data: planets farther from their star take longer to orbit, in agreement with Kepler's third law.

WRAP-UP — Synthesis and extension

Question / prompt	Suggested answer	Teacher note
Write one clear physical trend observed in the database.	Possible answers: "Longer period planets are generally farther from their star"; "Mass and radius form broad planetary families"; "Very high eccentricities exist but are less common than low to moderate ones."	Any real physical trend from the plots is acceptable.
Write one clear observational bias that affects the catalogue.	Model answer: "Close-in planets, especially large ones, are overrepresented because transit and radial-velocity methods detect them more easily than small, distant planets."	This is the most important bias in the activity.
Which family of exoplanets seemed easiest to identify?	A common answer is gas giants / hot Jupiters because they stand out clearly in both mass and detection bias. Some students may instead say sub-Neptunes because they form a visible population in radius-based plots.	Accept either if justified from the diagrams.
In 4–5 lines, explain why real astronomical data are powerful but must be interpreted carefully.	Model paragraph: "Real data are powerful because they reveal genuine patterns in nature, such as planetary families or Kepler's law. They also make students work like scientists by reading incomplete and noisy measurements. But a catalogue is shaped by selection effects: some planets are easier to detect than others. This means that the observed distribution is not exactly the true distribution in the Universe. Good interpretation therefore requires both graph reading and critical thinking."	Students do not need this exact wording. Reward the combination of "real patterns" + "bias / caution".

Extension activity: compare 51 Peg b and Kepler-10 b.	51 Peg b is a close-in giant planet (“hot Jupiter”), while Kepler-10 b is a very close-in small rocky planet. Together they show that planets at similarly small orbital distances can still be extremely different in mass, size and composition. Planetary systems are therefore highly diverse.	Shorter versions are fine if the contrast is clear.

Final teacher note The best student answers combine three ideas: (1) patterns in the plots are real, (2) those patterns are filtered by detection methods, and (3) exoplanet systems are much more diverse than the old “Solar-System-only” picture.

Useful reminder for correction

Key term	Simple correction-friendly definition	Comment
Semi-major axis	Average orbital distance, usually measured in AU.	Students can say “distance to the star” in simple language.
Eccentricity	Measure of how circular or stretched an orbit is; e = 0 means a circle.	Low e = nearly circular.
Log scale	Equal spacing means equal multiplication, not equal addition.	Useful whenever values span many powers of ten.
Detection bias	A distortion caused because some planets are easier to detect than others.	Core concept for this activity.