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7. Appendices

Appendix A. Final Version of the PFCI Version 3

The final version of the PFCI is presented here. This version is the same as Version 3 with the exception of item #9, which was revised so as to include distractors more aligned with known student reasoning difficulties (see Section 4.1).

Final Version of the PFCI

Directions:

Read the entire question and ALL of the answer choices carefully before selecting an answer. Fill in the bubbles completely! Each question has *one* correct answer unless otherwise specified.

Instead of writing your name on this form, fill in the numerical bubbles with the ***last four digits of your phone number*** (we will not be able to look you up with this information, and your identity will remain anonymous).

Enter last four digits below:

0	0	0	0
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9

1. How did the planets in our Solar System form?

- ☐ They formed from a collision between our Sun and a nearby star
- ☐ They formed from the energy and matter released at the same time as the Big Bang
- ☐ They formed from the collapse of a cloud composed of gas and dust
- ☐ They formed from the remains of a massive stellar (star) explosion
- ☐ They formed from material that was pulled in from a nearby solar system by our Sun

2. Which of the following statements is *FALSE*?

- ☐ A planet must orbit around a star (sun)
- ☐ A planet must have an atmosphere
- ☐ A planet must clear its orbit of surrounding debris
- ☐ A planet must be roughly spherical in shape

3. In our Solar System, what best describes the physical characteristics of Mercury, Venus, Earth, and Mars?

- ☐ These planets are dense, small, and are made primarily of hydrogen and helium gas
- ☐ These planets are dense, small, and are made primarily of rocks and metals
- ☐ These planets are dense, large, and are made primarily of rocks and metals
- ☐ These planets have low densities, are large, and are made primarily of hydrogen and helium gas
- ☐ These planets have low densities, are large, and are made primarily of icy material

4. Which describes how the locations (relative to the Sun) of the planets in our Solar System may have changed over time?

- ☐ They changed because space is constantly moving and expanding
- ☐ They changed because the planets are constantly colliding with each other
- ☐ The larger planets may have changed locations early in the Solar System's history because of the gravitational interactions between them
- ☐ The locations of the planets have not changed over time; they formed in the same locations they are in now

5. Which of these objects would you expect to find in our Solar System? (*CIRCLE ALL THAT APPLY*)

- ☐ Comets
- ☐ Asteroids
- ☐ Dwarf Planets
- ☐ Exoplanets
- ☐ The Milky Way Galaxy

6. Which of these scenarios best describes the general planet formation (accretion) process?

- ☐ Dust grains continuously collide, accumulate more mass, and develop into planets
- ☐ Material is ejected into the Solar System from an explosion, and this material forms the planets
- ☐ Once the planets grow large enough, the Sun's gravity causes the growing planets to accumulate all of the matter around them
- ☐ A pressure build up in the solar nebula due to the birth of our Sun leads to the formation of the planets
- ☐ At the time of the Big Bang, material collides, grows in size, and forms planets

7. For our Solar System, which statement is *TRUE* regarding which planet[s] completed their formation process first?

- ☐ Mercury formed first because it is the closest to the Sun, and Neptune formed last because it is the farthest away
- ☐ The rocky planets all formed together first, and then the gas giant planets started their formation millions of years later
- ☐ The gas giant planets all formed together first, and then the rocky planets started their formation millions of years later
- ☐ Neptune formed first because it is the farthest from the Sun, Mercury formed last because it is the closest to the Sun
- ☐ All of the planets in our Solar System formed at approximately the same time

8. What is the definition of an exoplanet?

- ☐ A planet at the edge of the Solar System
- ☐ A planet outside of our Solar System
- ☐ A planet no longer bound by gravity to its star
- ☐ A planet that is habitable
- ☐ A planet that does not clear its orbit of surrounding debris

9. Jupiter, Saturn, Uranus, and Neptune (the outer planets) were able to grow much larger than Mercury, Venus, Earth, and Mars because:

- ☐ In the locations where the giant planets formed metals, rocky minerals, and icy minerals were all able to solidify. As a result, all of these materials could be used to form the outer planets
- ☐ The gravitational force far from the Sun was much weaker, allowing the outer planets to grow to much larger sizes
- ☐ In the outer Solar System there was much more rocky material than icy material. This made it possible for the outer planets to attract their large gaseous envelopes
- ☐ During the Solar System's formation, the Sun ejected additional solids into the outer Solar System. These solids were eventually used to form the outer planets

10. During the planet formation process, what is the primary role of the force of gravity?

- ☐ Gravity helps bodies with enough mass attract surrounding dust and gas so they can continue to grow into planets
- ☐ Gravity is the force that causes denser, more massive planets to form closer to the Sun
- ☐ Gravity determines which material (e.g. metals and gas) will be prevalent at certain distances from the Sun
- ☐ Gravity keeps the growing planets from collapsing on themselves if they get too massive during the formation process

11. In our Solar System, what best describes the physical characteristics of Jupiter, Saturn, Uranus, and Neptune?

- ☐ These planets are dense, small, and are made primarily of hydrogen and helium gas
- ☐ These planets are dense, small, and are made primarily of rocks and metals
- ☐ These planets are dense, large, and are made primarily of rocks and metals
- ☐ These planets have low densities, are large, and are made primarily of gases and icy material
- ☐ These planets have low densities, are large, and are made of strictly hydrogen and helium gas

12. Which of these most accurately describes a planet?

- ☐ A planet orbits around another larger, rocky body
- ☐ A planet orbits around a star
- ☐ A planet is an object that is massive enough to fuse hydrogen into helium
- ☐ A planet must be able to sustain life

13. Why do the planets in our Solar System orbit the Sun in the same plane?

- ☐ The planets were ejected into this configuration at the time of the Solar System's formation
- ☐ The planets formed from a flattened disk-like structure, which caused the planets to orbit in this configuration
- ☐ The planets orbit around the Sun on retrograde orbits, and these orbits require the planets to be in the same plane
- ☐ The planets were pulled into this configuration by the gravity of nearby asteroids and comets

14. In our Solar System, why did rocky planets form close to the Sun while the gaseous planets formed further away?

- ☐ Close to the Sun, gravity was only strong enough to pull the rockier planets close in
- ☐ Close to the Sun, planets composed of mainly gas were incapable of remaining stable
- ☐ Close to the Sun, only heavy elements (like rocks and metals) could solidify at such high temperatures and eventually form a planet
- ☐ Close to the Sun, all of the gaseous material was used to create the young Sun, so there was no material left to form the gas planets close in

15. The planets in our Solar System orbit the Sun in _____ direction[s], at speed[s], and on _____ orbits.

- ☐ The same, different, elliptical
- ☐ The same, the same, elliptical
- ☐ Different, the same, circular
- ☐ Different, different, elliptical
- ☐ The same, different, circular

16. Which of these best describes how the composition of the planets in our Solar System changes with *increasing* distance from the Sun?

- ☐ Rocky Planets → Gas Planets → Icy Planets
- ☐ Gas Planets → Rocky Planets → Icy Planets
- ☐ Icy Planets → Rocky Planets → Gas Planets
- ☐ Rocky Planets → Icy Planets → Gas Planets
- ☐ Gas Planets → Icy Planets → Rocky Planets

17. When did our Solar System form relative to the Big Bang?

- ☐ Our Solar System formed before the Big Bang
- ☐ Our Solar System formed at the same time as the Big Bang
- ☐ Our Solar System formed immediately after the Big Bang
- ☐ Our Solar System formed a long time after the Big Bang

18. The discovery of exoplanetary systems has supported the idea that:

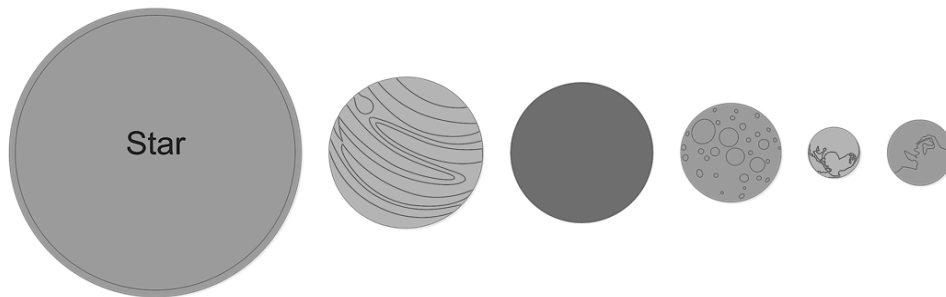
- ☐ Exoplanetary systems look exactly like our Solar System, with a combination of rocky and gaseous planets
- ☐ Exoplanetary systems look entirely different than our Solar System, with planets made of materials not found in our Solar System
- ☐ Exoplanetary systems must have Jupiter-sized planets orbiting close to their host stars
- ☐ Exoplanetary systems are different from our Solar System in that every planet discovered in these systems has the potential for life
- ☐ Exoplanetary systems are likely similar to our Solar System in terms of the general formation process, but the locations and compositions of the planets may be different

19. What is the definition of a dwarf planet?

- ☐ A planet at the edge of a solar system
- ☐ A planet outside of our Solar System
- ☐ A planet with an irregular orbit around a star
- ☐ A planet that is habitable
- ☐ A planet that does not clear its orbit of surrounding debris

20. Below is a depiction of a hypothetical solar system. Based on the image below, which of the following answers correctly describes why the planets are in the locations shown?

NOTE: The sizes of the planets/star are not to scale relative to the distances between them.



- ☐ All of the planets in this solar system formed exactly where they are shown
- ☐ The largest planets in this solar system moved inward during the formation process due to planetary migration
- ☐ The largest planets in this solar system moved inward during the formation process because the Universe is constantly moving and expanding
- ☐ The strong gravitational pull of the star caused the large and small planets to switch positions

21. Which of the following best characterizes your academic major(s)?

- ☐ Science major (e.g. physics, chemistry, biology)
- ☐ Non-science major (e.g. history, business, dance, etc...)
- ☐ Double major
- ☐ Undecided
- ☐ Other

22. What gender do you identify with?

- ☐ Male
- ☐ Female
- ☐ Non-binary
- ☐ Non-conforming
- ☐ Other

23. Have you ever taken a course besides this course that covered the topic of planet formation?

- ☐ Yes, in high school
- ☐ Yes, at a 4-year college
- ☐ Yes, at a community college
- ☐ Yes, other
- ☐ No