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How Gravity Impacts Life

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Introduction

Every student arguably has heard of the word "gravity," and seemingly understands the idea that it is an invisible but physical force that pulls humans and all other objects of mass down to the ground, and towards the center of the Earth. However, it is not often that teachers present gravity as an "evolutionary force" that is both necessary and essential for life to exist, evolve, grow, and reproduce. Recent research supports the claim that gravity plays a deciding factor on the sizes, heights, and shapes of living things, as well as the specific locations of vital organs like our hearts.[2] For instance, crawling insects have developed adhesive mechanisms such as hairy pads to overcome the friction forces of the ground as they travel, while humans need an inverted pendulum mechanism to counter the effect of gravity as we stand and walk.[3]

The three essential questions for this interdisciplinary unit that integrates Science with Math and ELA standards include: 1) What is gravity? 2) How does gravity affect life and space travel? 3) Does it play a role in evolution? The unit is designed with 10 lessons for the span of 2-3 weeks.

By studying how gravity impacts the evolutionary journey of life on Earth, we can begin to imagine how alien life could emerge in other planetary systems. Throughout this unit, students will address the effects of gravity with teacher's direct instruction, student-centered learning centers, peer-to-peer support, math calculations, model-making, discussion, and opinion writing. For examples, students will record root causes of microgravity on the health of astronauts in their science journals, build a large-scale Solar System model to understand gravitational forces, and write an evidence-based argument to defend why a heavier (more massive) or a lighter (less massive) Earth-like exoplanet is the more desirable residence for humans.

Rationale

There are multiple reasons why this unit is so meaningful for me to write, and share with other educators. **The major reason** is that the gender, racial, and income disparities in our school system inevitably set students like my 5th graders in Philadelphia to fail in school, especially in the science, technology, engineering, and math (STEM) disciplines. These disparities need to be addressed as a global urgency in order to advocate free and equal education for all children. According to the 2019 National Science Board's data, men continue to dominate the STEM fields with 73% representation, even though women made up nearly 50% of the U.S. workforce; women had made slow progress from 8% in 1979 to 34% in 2019 of the STEM workforce.[4] Similarly, the racial disparity is undeniably disconcerting: Whites represent 65%, Hispanics 14%, Asians 9%, and Blacks 9% of the STEM workforce.[5] Blacks and non-white Hispanics with a bachelor's degree or higher in STEM are disproportionately underrepresented, relative to their overall U.S. population.[6] For low-income students, they are more likely to attend low-income schools with limited access to STEM resources, classes, and opportunities.[7] For other marginalized groups like the LGBTQ+ STEM community, 32.9% experienced harassment at work compared to 22.7% of their non-LGBTQ peers.[8] So what are the "root causes" for these unjust disparities? Besides the obvious discriminatory environments, many reports mentioned deficient K-12th Math and Science education as a contributing factor to the stagnant graduation rates in STEM for those who are female, a member of a racial minority, from a low-income family, and/or a member of the LGBTQ+ community.

I want to use this unit to inspire ALL students to think of themselves as future space travelers and global citizens, especially those who feel they are marginalized and underrepresented in the fields of science. Students should learn about the great accomplishments and international collaboration of the National Aeronautics and Space Administration (NASA), European Space Agency (ESA), Canadian Space Agency (CSA), Russian Federal Space Agency (Roscosmos), and Japan Aerospace Exploration Agency (JAXA) in the International Space Station (ISS). Students should also be introduced to the many pioneers like Ed Dwight, Jr. (1933, age 88) who is now described as "the almost first black astronaut," Ruth Bates Harris (1919-2004) who was fired for her whistleblowing on NASA's discriminatory hiring practices, and the controversy surrounding NASA's refusal to rename the James Webb Space Telescope. Below are examples of videos and articles that can serve as catalysts to discuss the gender and racial disparities in STEM: 1) *The Color of Space: a NASA Documentary Showcasing the Stories of Black Astronauts*, https://www.youtube.com/watch?v=S6vYHdH0AeE; 2) *I Was Poised to be the First Black Astronaut*, www.youtube.com/watch?v=Xj1sJQW98nE; 3) *Ruth Bates Harris, a Whistle Blower for Equality*, https://historicsites.dcpreservation.org/items/show/1007; 4) *Who Is James Webb?* https://www.nbcnews.com/nbc-out/out-news/was-james-webb-scientists-want-rename-james-webb-space-telescope-rcna37838; 5) and *NASA Astronauts Celebrate Asian American & Pacific Islander Heritage Month*, www.youtube.com/watch?v=tuDPzaiD6qQ.

The **second important reason** is that I want to address the gender stereotypes and biases that "boys are better than girls in math and science." Most boys (unfortunately not as many girls as I would like) had once dreamt of becoming an astronaut flying into space. Students (especially girls) learn at a young age that if you are not good at math, then you are not good at science. Equally-biased is the fact that when a student struggles with reading and writing, they are immediately labelled "dumb" or "stupid." According to the World Space Flight's website, as of August 2022, there are 628 people (citizens from 42 countries) who have been to space based on the United States Air Force's (USAF) definition; and 615 people.[9] On a NASA's webpage celebrating Women's History Month, it reads: "As of March 2022, 75 women have flown in space, including cosmonauts, astronauts, payload specialists, and space station participants."[10] During the Space Race, Soviet cosmonaut Yuri Gagarin (1934-1968) became the first man in space on April 12, 1961, and just a month later, on May 5th , Alan B. Shepard (1923-1998) became the 1st American astronaut in space.[11] It took twenty-two (22) years later in 1983 for Sally Ride (1951-2012) to become the 1st American woman astronaut to fly in space, and the 3rd woman after Valentina Tereshkova (1937, age 85) in 1963, and Svetlana Savitskaya (1948, age 73) in 1982.[12] Ride was once quoted in a 2004 interview: "…that if we want scientists and engineers in the future, we should be cultivating girls as much as the boys, and that we needed to be able to give girls in middle school, high school and college the same opportunities that we give to boys."[13] It was only after her death that Ride was acknowledged as the 1st gay astronaut in her obituary written by her lifelong partner, Tam O'Shaughnessy.[14] Today there are only 75 female astronauts (compared to 628 astronauts overall) in the world, and a simple calculation reveals how women still have a long way to go with only 12% female astronaut representation when 49.58% of our World Population are women.[15] Also, space tourism is now available to the wealthy few who are willing to pay more than $50 million per seat.[16]

The **third reason** has to do with how science is taught (or not taught at all), especially in the elementary grades. Science instruction is often put on the back burners due to the heavy emphasis on Math and ELA standards; most K to 8th students receive less than 45 minutes daily science instruction. Furthermore, teachers are not properly trained in science content and inquiry pedagogy to teach the subject effectively. Many teachers have to advocate for new science resources on their own, or teach from outdated textbooks. About 6 years ago, I participated in a teachers' training program about the Sun and Earth; it was not mandated by my district, but a volunteer pilot program to test out the Full Open Science System (FOSS) and other research-based science curricula for district-wide implementation. So far, there has been no new updates about this initiative. While a new scientific discipline like astrobiology (also known as exobiology and bio-astronomy) is gathering astronomers, biologists, physicists, geologists, and other scientists to take on a multidisciplinary approach to study life in space, traditional public schools continue to take on a departmentalized approach to marginalize science learning into silos that are separated from students' lives. On paper, the departmentalized-silo approach seems to make sense to maximize instructional time and lessen teacher workload, but in reality, 45 minutes of daily science instruction is ineffective and short-sighted. Until science is treated as an integral and vital part of daily learning with connections to Math and ELA, students will not be able to gain a more holistic understanding of our world, a greater awareness of different perspectives, and a better application of science to real-life problems. The ultimate goal of this unit is to help all students to have a better view of themselves as capable math thinkers, creative writers, and young scientists who possess ideas, contributions, and solutions to new inquiries like how gravity impacts life in our shared Universe. Schools need to enhance the scope and depth of science learning with more engaging, and less irrelevant content. I believe my curriculum unit can empower other educators to teach a thought-provoking scientific inquiry about gravity.

Demographics

My school demographics represent a highly diverse community with a wide range of cultural and language backgrounds. We are a Title One high-poverty K to 6th public school located in Philadelphia. The languages spoken by this diverse group of multilingual students, teachers, administrators, and parents include: Arabic, Burmese, Chinese, French, Hindi (India), Indonesian, Italian, Karen (Myanmar), Khmer (Cambodia), Korean, Laos, Malays, Chichewa (Malawi), Nepali, Pashto (Pakistan), Spanish, Swahili, Thai, Turkish, Vietnamese, and other indigenous languages. In the 2021-2022 school year, we have an enrollment of 417 students with 43% female and 57% male, and about 40.8% Hispanic, 38.6% Asian, 9.6% White, 8.2% Black, and 2.9% Multi-

Racial: that's a total of 90.4% minority students.[17] About 71.4% are English Language Learners (ELL), 5% had exited out of ELL services, and 15% are children of immigrants who are American-born (these students were never classified to receive ELL services, even though a language other than English is primarily spoken at home.)[18] That's an estimate of 90% of our student body is recent immigrants and/or children of immigrants. Due to the high percentage of multilingual learners, I rely a lot on hand-on activities, visual aids, and ELL strategies to make learning more meaningful and active for my students.

Content Objective

Question #1: What Is Gravity and the Basic Laws It Follows?

So, what exactly is gravity? At the most basic level, gravity (gravitational force) is the universal attraction between all matter. Matter is anything that has mass and volume. Mass is the amount of substance. Volume is the amount of space that a substance occupies. A gravitational force is an attraction (a pull) acting upon an object as a result of its interaction with another object. For instance, the Earth's gravity draws objects of smaller mass towards its center. Gravity keeps our Moon orbiting around the Earth, our Earth and other planets orbiting around the Sun, and all the stars in our Galaxy orbiting around its center.

The universal gravitational constant (denoted by the uppercase letter "G") is the force of attraction between two bodies of 1 kilogram (kg) that are 1 meter (m) apart anywhere in the Universe, and its value is always $6.67430\ (15) \times 10^{-11}\ Nm^2/kg^2$ (Newton-meter^2 per kilogram^2).[19]

Earth's acceleration due to its surface gravity (denoted by the lowercase letter "g") is the acceleration of a body experiencing free fall under Earth's gravitational force and its value is approximately $9.8\ m/s^2$, and it is sometimes denoted as 1g or mistakenly as 1G where G is not the gravitational constant, and should not to be confused with 1G, the first-generation wireless phone technology.[20] Reminder: "G" and "g" are two separate and independent entities and, therefore they are not the same units of measurement. For example, since the Moon has a smaller mass than the Earth, its surface gravity is about 1/6 (16.6%) as powerful as Earth's gravity or about $1.6\ m/s^2$ or "0.166 g" where "g" acts as a unit of measurement that compares arbitrary forces to the force of Earth's gravity.[21] Moreover, Earth's surface gravity is not a constant value because Earth is not a perfect sphere, and its mass is not distributed equally. The value of g-force on Earth varies depending on the location. For examples: 1) the gravity at the equator is weaker than the gravity at the poles; 2) the gravity at the top of Mount Everest is less than $9.8\ m/s^2$ due to its greater distance from the Earth's center.[22]

Four Fundamental Forces of Nature

There are four fundamental forces in nature. The four forces in the order from the strongest to the weakest are: 1) the strong nuclear force, 2) the electromagnetic force, 3) the weak nuclear force, and 4) gravity.[23] The strong nuclear force holds protons and neutrons together in the nucleus of an atom.[24] Electromagnetic force (emf) is the result of attraction or repulsion of charged particles (positive or negative charges) interacting together where the strength of the force is inversely proportional to the distance between the charges.[25] In incredibly short distances that are less than the diameter of a proton, the weak nuclear causes the radioactive decaying of unstable nuclear particles through time.[26]

Imagine the force needed to lift your feet off the ground from Earth's gravity. Easy, right? Now imagine the amount of physical force you would have to exert in order to pull the positive and negative charges of two magnets apart or push the positive and positive charges (or negative and negative) together. These mental pictures can help students understand why gravity is so weak. In fact, a drop of water can cling to the tip of your finger without falling to the ground. That's because the strength of the hydrogen bonding in water (a weak electromagnetic force) can overpower the force of Earth's gravity.[27] Another example: Gravity wants to crush the Earth into denser mass and smaller volume, but the strength of the electromagnetic forces inside atoms is so much greater that it resists the crushing by gravity.[28] That's why static electricity can make your hair defies gravity. The strong force's relative strength (based on a proton-proton pair) is about 100 times as strong as electromagnetism; 10^{13} times as strong as weak nuclear force; and 10^{38} times as strong as gravitational force.[29] In fact, gravity is so weak at the atomic scale that scientists can ignore it without making significant errors in their calculations.[30] For many years, physicists like Steven Weinberg (1933-2021), Abdus Salam (1926-1996), Sheldon Lee Glashow (1932, age 89), and recently Helen Quinn (1943, age 79) had attempted to prove that these four basic forces of nature are simply the "same universal force" guiding our Universe.[31]

However, at the astronomical scales, gravity does dominate over the other forces due to two reasons: 1) gravity has a long range (think distance between the Sun and Earth); 2) there is no such thing as negative mass.[32] Of course, there are now theorists who are investigating if negative mass supports the existence of dark matter.[33] Outside the short range of the atomic nucleus ($< 10^{-15}$ meters), the strength of both strong and weak forces quickly drops to zero. In contrast, even though the Sun and the Earth are 94.208 million miles apart, the gravitational force between them keep the Earth rotates around the Sun. Electromagnetism also has a long range like gravity, but it cannot be the force that keeps the Earth rotates around the Sun because positive and negative electric charges tend to cancel out, making most objects electrically neutral.[34] For objects more massive than one-fifth of the Earth, gravity (not electromagnetism) will dictate its shape, and most massive objects are likely to be spherical or elliptical.[35]

Gravity Observations from Galileo Galilei and Thomas Andrew Knight

During the early 1700s, Galileo Galilei (1564-1642) recorded how Earth's force (gravity) influences life structures and processes. Galileo's main contribution was to show that when objects fell, they picked up speed, in other words, he discovered acceleration is due to gravity.[36] Galileo also concluded that the ratio of length to width from animal bones of different weights deviated greatly among light and heavy animals.[37] In the late 1700s, the horticulturist Thomas Andrew Knight (1759-1838) was the first to record the effect of gravity on plants by simulating microgravity with the centripetal force of a rotating waterwheel, and observed that roots of plants grew parallel to the resultant gravity vector.[38]

Kepler's Laws for Planetary Motion

Johannes Kepler (1571-1630) was a German astronomer who best known for the laws of planetary motion. Kepler's 1st Law states: Each planet moves around the Sun in an elliptic orbit and the center of the Sun is one of two foci of this ellipse.[39] Kepler's 2nd Law explains that the orbital speed of a planet increases when near the Sun, and decreases when farther from the Sun where a line segment from the Sun to the planet sweeps out equal areas of the ellipse in equal intervals of time.[40] Kepler's 3rd Law ($P^2 \propto a^3$) says that the squares of a planet's orbital period (P^2) is directly proportional to the cubes of the semi-major axes of its orbit (a^3).[41]

Kepler's 3rd Law implies that if the planet’s orbit decreases in size, then it will take less time to orbit around the Sun. That is why Mercury (the innermost planet) takes only 88 days to rotate around the Sun, Venus takes 224 days, Earth takes 365 ¼ days, Mars takes 687 days, Jupiter takes 4,332 days, Saturn takes 10,759 days, Uranus takes 30,681 days, and Neptune takes 60,193 days.[42]

Isaac Newton’s Universal Law of Gravitation

Isaac Newton unified the work of Galileo, Kepler, and other modern scientists of his times into his Universal Law of Gravitation. In 1687 Isaac Newton (1642-1727) described how gravity acts between all objects of mass with this equation: $F = G\,Mm/d^2$ where “F” is the force of gravity, “G” is the universal gravitational constant, “M” is the mass of an object, “m” is the mass of the second object, and “d” stands for the distance between the two objects; this equation is now known as Newton’s Universal Law of Gravitation.[43] The universal gravitational constant (G) was first calculated in 1798 to be $6.6743 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$ by Henry Cavendish (1731-1810) who used a torsion balance designed by the physicist John Mitchell.[44] This equation explains gravity on the scale of our Universe, stating that a force of gravity attracts one mass with another mass varies directly as the product of the two masses and inversely as the square of the distance between the two masses. Billions of stars including our Sun create the gravitational pull of our whole Milky Way Galaxy that can make other smaller galaxies orbit around our Galaxy. The equation also explains that the gravitational attraction between two bodies (for example: the Sun and Earth) must be proportional to their masses.The more mass an object has, the stronger the pull of its gravitational force; that is why the Sun with its greater mass pulls the Earth to orbit around it. Newton’s Universal Law of Gravitation also implies that the gravitational attraction between two masses can get weaker with greater distance, but never to zero because both masses will continue to act on each other no matter how far away they get.[45]

In addition to Newton’s Law of Universal Gravitation, there are three Newton’s laws of motion that state: 1) an object will not change its motion unless a force acts on it, also known as the law of inertia; 2) the force on an object is equal to its mass times its acceleration ($F=ma$ where “F” stands for force of gravity, “m” for mass, and “a” for acceleration); 3) For every action, there is an equal (in size) and opposite (in direction) reaction, also known as the action-reaction law where forces come in pairs.[46] Newton’s third law of motion is consistent with his Law of Gravitation where the magnitude of the force (F) on each object is the same, even when one object has a larger mass than the other object. For instance, when Earth exerts a force of 9.8 N on an object of mass of 1 kg, that object will exert an equal force of attraction of 9.8 N on Earth.[47]

Albert Einstein’s Theory of General Relativity

What does the world’s famous equation $E=mc^2$ really mean? Why is the knowledge that “energy equals mass times the speed of light squared” so ground-breaking? Basically, the equation is saying: energy can turn into mass, and mass can turn into energy. Energy and mass are the same thing in different forms; they are interchangeable when the conditions are right. That’s how Nature works, even though humans can’t actually see energy such as gravity, heat, or light turning into mass of objects like an apple, our Moon, or our Sun. Albert Einstein (1879-1955) took 10 years of thinking and problem-solving to come up with the Theory of General Relativity; he first published an early version called the Theory of Special Relativity in 1905 (with the world’s famous question $E=mc^2$), but he didn’t count gravity into his calculations.[48] In 1907, Einstein had “the happiest thought of my life” while sitting on a chair: “If a person falls freely, he will not feel his own weight.”[49] This phenomenon speaks of the weightlessness feeling that is common to astronauts flying in orbit. Einstein expanded his Theory of Special Relativity to publish the Theory of General Relativity in 1915. Einstein’s theory explains how massive objects like stars and planets warp the fabric of space-time, a distortion that manifests as gravity.[50] Later in 1922, Alexander Friedmann (1888-1925), a Russian mathematician and meteorologist published a paper that outlined the possibility that an expanding universe started from a singular point.[51] On the largest scale where gravity has infinite range, our Universe is expanding rather than being pulled together by gravitational attraction. The renowned black hole physicist, John Wheeler (1911-2008) summed up the Theory of General Relativity this way: "spacetime tells matter how to move; matter tells spacetime how to curve"[52]

Today, most scientists still agree with Einstein's General Theory of Relativity, but recognize that Newton's Universal Law of Gravitation has limitations like it does not explain the existence of black holes.[53] Einstein's theory does, and black holes have been observed since 1964, including Sagittarius A*, a very massive black hole at the center of our own Galaxy.[54]

Question #2: How Does Gravity Affect Our Bodies and Space Travel?

Our human body is a living machine made up of systems with vital organs working together to keep us alive. Some of these systems and vital organs include: cardiovascular (heart), digestive (liver and stomach), endocrine (glands), immune (bone marrow, spleen and skin), muscular (muscle), nervous (brain), reproductive (ovaries and testicles), respiratory (lungs), and skeletal (bones).[55] NASA performs space trainings on Earth with artificial gravity (hypo-gravity or hyper-gravity) ranging from orbital flight, parabolic flight, head down/head up tilt, head, body loading, centrifugation, to swimming in deep tanks.[56] When astronauts travel into space, gravity on their bodies is altered, resulting in microgravity, a state of very low acceleration between two free-falling objects. Hypo-gravity is a related term that usually describes the change of acceleration that passengers experience inside an aircraft for a short time during a parabolic flight that usually produces about 25 seconds of free-fall (0 g) followed by 40 seconds of enhanced force (1.8 g) in a repeated cycle.[57] Even though both the astronauts and the aircraft's passengers experience weightlessness, microgravity happens in space and hypo-gravity happens artificially inside an aircraft. Another form of altered gravity is hyper-gravity which means gravity greater than the acceleration of 1g on the surface of the Earth.[58] Examples of hyper-gravity include centrifuge training for astronauts, and animal centrifuge lab experiments. Since electromagnetism and gravity are linked phenomena, altering gravity may also alter electromagnetism.

Mass v. Weight

In science, mass and weight are not the same, even though weight is proportional to mass. When you step on a scale in a doctor's office, you are actually measuring "your mass" and "not your weight. Another way to remember the difference is: mass is always the same (a constant value), but weight changes depending on the acceleration of Earth, or Moon, or in space. A person's weight is six times greater on Earth than on the Moon. If you weigh 120 pounds (lb.) on Earth, you would weigh about 20 lb. on the Moon. Mass (m) is the amount of "matter" in an object, but weight (W) is the force exerted on an object by gravity. Here is a video explanation: https://www.youtube.com/watch?v=U78NOo-oxOY.

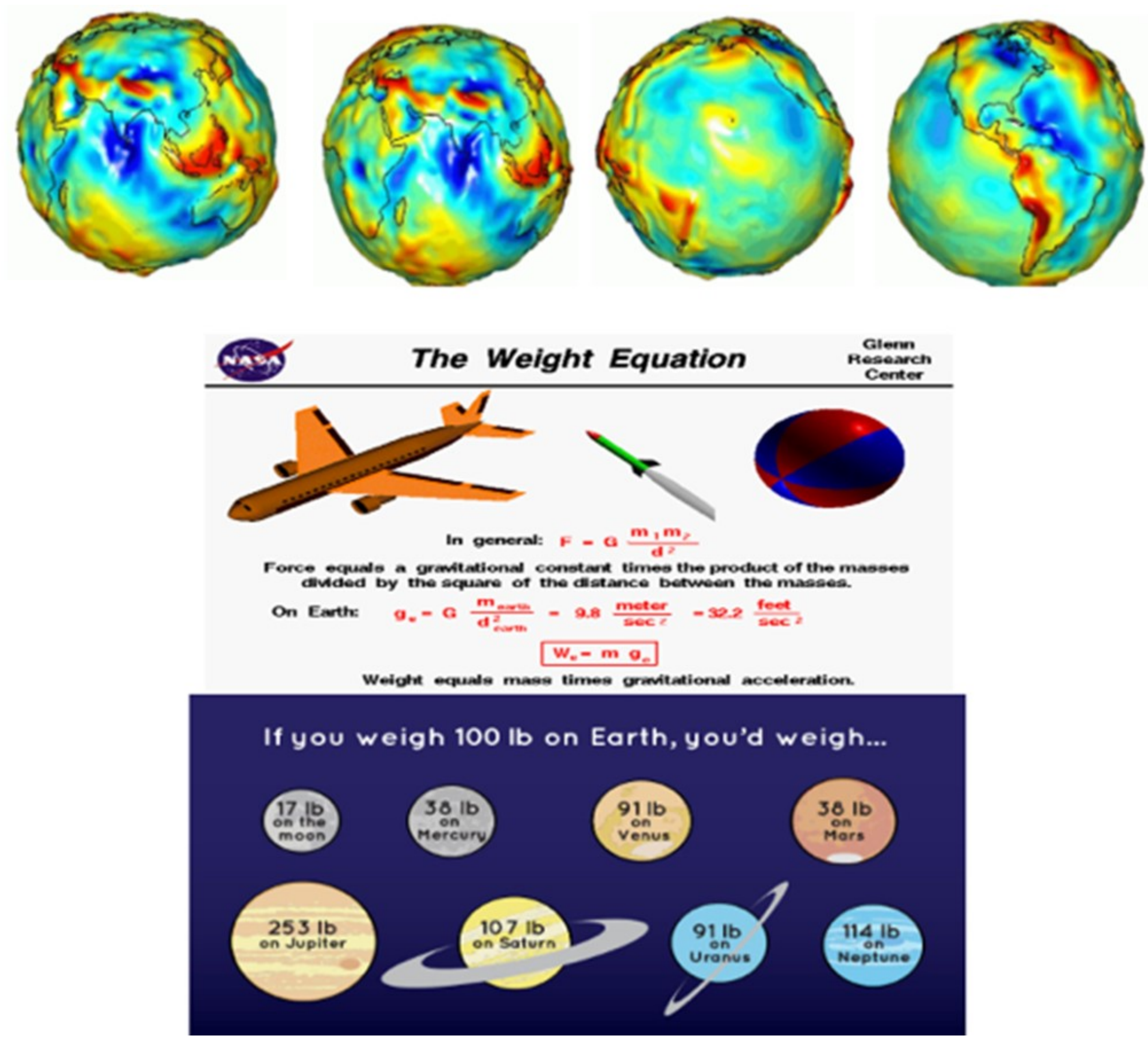


Figure 1: (Top) The colors of these globes represented how Earth's surface gravity varies in value depending on the location; these images were captured by NASA's Gravity Recovery and Climate Experiment (GRACE), visit https://grace.jpl.nasa.gov/resources/6/grace-global-gravity-animation/ to see a 3D animation.[59] (Middle): This illustration from NASA's Glenn Research Center explains how the Weight Equation "W=mg" is derived from Newton's Universal Law of Gravitation $F = G\ m_1m^2 /d^2$ where W of earth is 9.8 m/s^2 and the equation is also similar to Newton's 2^{nd} law of motion, F= ma.[60] (Bottom): A comparison of how much a 100 pounds person would weigh on the Moon and other planets.[61]

Tides Due to the Moon's Gravitational Force

Why do oceans have high and low tides? The answer has to do largely with gravitational forces exerted on the Earth's oceans by the Moon, and to a lesser extent by the Sun. Since the Sun is 27 million times larger than the Moon, the Sun's gravitational attraction to Earth is more than 177 times greater than that of the Moon's pull on Earth.[62] However, because tide-generating forces vary inversely as the cube of the distance from the object, and the Sun is 390 times further away to the Earth than our Moon is to the Earth, the Sun's tidal force is reduced 390^3 (about 59 million times).[63] That's why tides have more to due to the Moon's pull on Earth than the Sun's. In short, tides are caused by differences in gravitation between the Earth and the Moon. The part of the Earth facing the Moon experiences a larger gravitational force than that of the opposite side of the Earth; this difference is the tidal force which causes the Earth's closest side to the Moon to bulge towards the Moon.[64] High tides are made when the highest point in the wave (the crest) reaches a coast, while low tides are made when the lowest point (the trough) reaches a coast. There are also tides in other bodies of water like lakes, ponds, and rivers, but the gravity impact is so minimal that it is difficult for our naked eyes to detect.[65] Does the Moon's gravitational force impact human health? As of now, there is no reliable scientific proof that the Moon affects human's mood, sleep, women's menstrual cycle, and any other mental and physical health issues.[66] However, some organisms like corals seem to time their reproduction cycle with the lunar cycle, but the conclusion seems to be that the Moon's gravitational force is too small to adversely impact human's health and behavior.[67]

Weightlessness, Microgravity and other Altered Gravity

In space, astronauts have to be concerned with the phenomenon called microgravity or weightlessness. The terms weightlessness does NOT mean "zero gravity" or "no gravity." Plus, there is no such thing zero gravity. A common misconception about spacecraft orbiting the Earth is that they are operating in zero-gravity, an environment with no gravity which is misleading. The sensation of weightlessness experienced by astronauts is not the result of zero gravitational acceleration (remember Newton's Universal Law of Gravitation), but that the astronauts cannot feel the g-force because there is no difference between the acceleration of the spacecraft and the acceleration of the astronauts. This is why when we go down in an elevator, for a few seconds we feel as though our weight has decreased. You can also think of it this way: the Earth is rotating very fast with one rotation in 24 hours, but we do not feel the Earth's rotation since we are rotating at the same rate as the Earth. The feeling of weightlessness is exactly analogous to standing on Earth and doesn't feel like we are rotating around the Sun.

Unlike the Sun which appears to rise and set, an object like a spacecraft appears motionless in the sky from Earth, looking as if it is defying gravity. In actuality, the spacecraft is moving in a circular orbit at about 35,785 km above Earth's equator, and its orbital period is equal to Earth's rotation period of 23 hours and 56 minutes.[68] James Oberg (1944, age 77), a space journalist explains the phenomenon called geostationary this way: "The myth that satellites remain in orbit because they have "escaped Earth's gravity" is perpetuated further (and falsely) by almost universal misuse of the word "zero gravity" to describe the free-falling conditions aboard orbiting space vehicles."[69] Earth's gravity keeps satellites from flying off into space. When our naked eyes see a satellite flowing in space, seemingly "weightless," it's because we are not able to see the satellite's resistance of gravitational pulls from Earth. In other words, gravity exists in space, inside a spacecraft, around satellites, and is everywhere in our Universe, even inside the supermassive black hole at the center of our Milky Way Galaxy.

NASA's Preventive Measures Against the Effects of Microgravity

Humans are used to Earth's gravitational acceleration of 1g, but astronauts in space have to learn how to deal with microgravity. NASA has recorded that some astronauts who went to space for an extensive amount of time returned taller (in height) with reduced bone and muscle mass at the rate of 1% bone loss per month; some had memory loss and learning difficulties due to the increased pressure on the brain, and poorer immune system that weakens the function of T-cell.[70] A list of other negative effects of microgravity include: 1) space adaptation syndrome (space sickness) with symptoms of nausea, vertigo, and lethargy; 2) loss of muscle mass (muscle atrophy); 3) loss of bone mass (osteoporosis); 4) eyesight problem; 5) "moon-face" due to blood rushing to the head; 7) plague buildup inside arteries; 8) and cancer.[71] According to a NASA study (2012), spaceflights may also be harmful to the brains, and accelerate the onset of Alzheimer's disease.[72] Researches on the impact of gravity on human physiology may help scientists to figure out how to detect life in the space.

In microgravity, there is less weight load on the back and leg muscles, so these muscles and bones will weaken and shrink. Muscles degeneration and bone osteoporosis can be rapid for astronauts during a space mission, and without regular exercise astronauts may lose up to 20% of their muscle mass within 5 to 11 days, and 1.5% of bone density per month (compared to about 3% in 10 years for a healthy person in a healthy environment).[73] The mass loss mainly affects the lower vertebrae of the spine, the hip joint, and the femur. Unlike patients with osteoporosis, astronauts who are in space for 3 to 4 months can later regain their normal bone density after a period of 2 to 3 years back on Earth.[74] After returning to Earth, bone loss might not be completely corrected by rehabilitation; however, with proper diet and exercise, their risk for fracture is not higher than the risk of people who never experienced microgravity. On Earth, bones are destroyed and renewed regularly with a well-balanced system of bone destroyer cells and bone building cells; whenever bone tissue is destroyed, new layers take their place.[75] When in space, the natural process of destruction and construction of bone cells is altered, and because an increasing number of bone building cells is lost, the bones decompose into minerals that are then absorbed into the body. The increase in calcium levels from the disintegrating bone causes a dangerous calcification of soft tissue and increases the potential of kidney stone formation; NASA is studying medicines like potassium citrate to help combat this risk.[76]

The best way to study the effects of microgravity is to create artificial gravity. To date, scientists have managed to create gravity only under laboratory conditions, using strong magnetic fields. Astronauts will encounter three basic gravity fields on a mission to Mars. On a 6-month trek from Earth to Mars, a space crew would feel weightlessness due to microgravity. While living and working on Mars, the crew will be living in a gravitational field about one-thirds of Earth's gravity. In the movie "The Martian," the spaceship had a rotating circular structure that has gravity equal to 40% of what would be on the Earth.[77] Even though the Mars' gravity isn't extreme, living on the Mars with the gravity weaker than Earth's could be dangerous to humans, causing long-term health issues, and may be even negative impacts on human fertility.[78] When shifting from weightlessness back to Earth's gravity, astronauts will have to re-adapt to Earth's gravity, and the transition may be difficult. Astronauts may experience "post-flight orthostatic intolerance" where they may feel poor hand-eye coordination, spatial disorientation, lightheaded, unable to maintain their blood pressure and balance when standing up.[79] For example, a full EVA (extravehicular activity) spacesuit weighs about 280 pounds on Earth during training, but weighs close to nothing in the microgravity environment of space.[80] When astronauts are in their EVA spacesuits, they also wear anti-nausea patches because vomiting inside the suit can be a deadly choking hazard, and that's why space suits are worn mostly during launching, landing, and doing activity outside the spacecraft.[81] Sea sickness drugs can help to treat space sickness, but are rarely used because the natural adaptation is preferred during the first two days of space travel over side effects such as the drowsiness caused by the sea sickness drugs.[82]

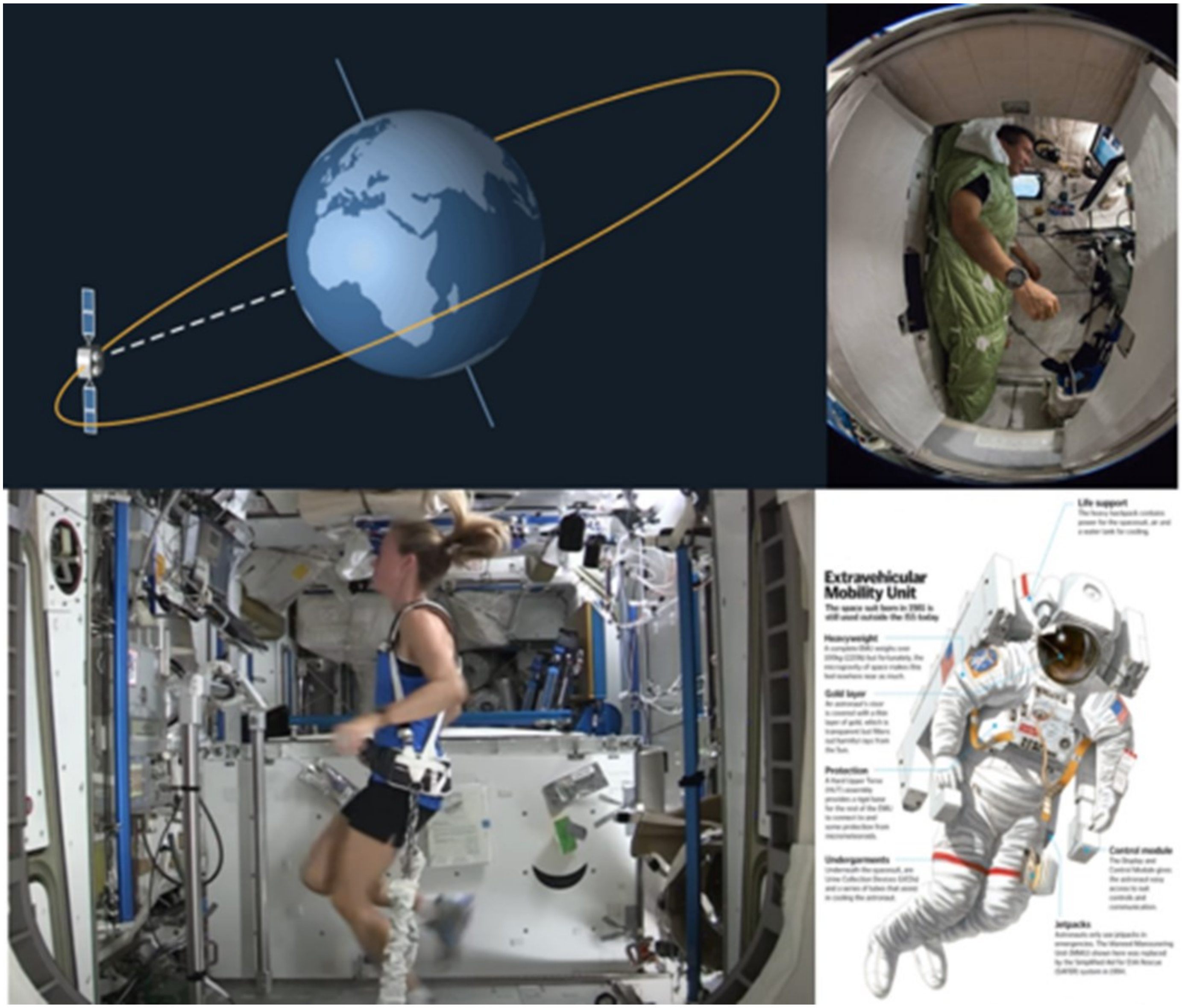


Figure 2: (Top Left) This simulation shows how the ISS orbits around the Earth. The ISS circles the Earth about 15.5 times a day and each orbit takes about 93 minutes.[83] (Top Right): Astronauts sleep inside sleeping beds in tight compartments and their bodies are strapped down to prevent flowing.[84] (Bottom Left): NASA astronaut Karen Nyberg demonstrates how astronauts run in space on the COLBERT Treadmill. (Bottom Right): A spacesuit is more like a mini-spacecraft than a jumpsuit. This 1981 spacesuit named Extravehicular Mobility Unit (EMU) is still being used today, and was designed to be heavyweight to counteract microgravity.[85]

The weekly schedule of astronauts in the ISS is about 5.5 work days and 1.5 days off. Most work days are consisted of 8.5 hours of sleep, 6.5 hours of work, 2.5 hours of exercise, and an hour for lunch.[86] The ISS has apparatus for astronauts to perform at least 2 hours of resistance training per day; the exercises include jogging on a treadmill while attached to a giant elastic bands, riding a stationary bicycle, and lifting weights.[87] Aerobic and resistive exercises help astronauts keep their hearts, bones, and muscles strong, minds more alert, as well as a more positive outlook against the feelings of isolation, confined spaces, and possibly depressive thoughts. In microgravity, the fluids in the body can shift upward to the head putting pressure on the face, eyes, and ears which can cause headaches, vision and hearing problems. Astronauts wear compression cuffs on their thighs or pants that put pressure on their leg bones to keep blood in their lower extremities. Other ways to counteract microgravity include: using a pressure device to draw fluids from the head into the legs, performing spinal ultrasound screening to monitor back pain, and conducting MRI imaging to assess muscle size and bone density.[88] Due to dehydration and calcium excretion, the body may develop kidney stones, therefore, urine is collected and measured daily to help astronauts to make modifications to their diet, water intake, and exercise routine.[89] Since medications like bisphosphonate has been used successfully to reduce bone breakdown and prevent kidney stones in patients on Earth, NASA has cautiously extended the use of such medications for astronauts in space mission.[90]

Super Earths v. Earth-Like v. Mars-Like Exoplanets

As of August 2022, NASA's website has acknowledged 5,063 confirmed exoplanets and 3,794 planetary systems.[91] A habitable exoplanet is a planet that has liquid water, a stable star, the right mass and temperature, the ability to hold an atmosphere, and located in the Goldilocks Zone that is "not too close, no too far from its host star, but in just right conditions for life to exist."[92] Stars are classified according to their surface temperature into spectral types: (hottest) O-type, B-type, A-type, F-type, G-type, K-type, to M-type (coolest); these 7 spectral types are further divided into 10 subclasses (0 to 9, hottest to coolest).[93] Under the Morgan-Keenan luminosity class system, stars are measured by its energy radiation (brightness) and each star was originally designates with Roman numerals from "I" (super giant star) and "V" (main sequence), but now further into subgroups: Ia-0, Ia, Ib, II, III, IV, V, VI or sd, and D.[94] This order goes from: extremely luminous super giants, luminous super giants, less luminous super giants, bright giants, normal giants, sub-giants, main sequence dwarf stars, sub-dwarfs, to white dwarfs.[95] The classification for our Sun is G2V, yellow-white in color with surface temperature about 6,000 degrees in Celsius, and a hydrogen-burning main-sequence star. The Hertzsprung-Russell (HR) diagram is a helpful tool that plots the star's spectral type and luminosity on a graph. F, G, and K-type stars are more likely to host habitable exoplanets.[96] G-type stars like our Sun would host exoplanets most similar to Earth, K-type stars would host Super-Earths, M-type stars may be able to host an exoplanet like Proxima Centauri b, and flare stars (mainly dim red dwarfs and a few brown dwarfs) could erode making their atmospheres inhabitable.[97]

The five basic types of exoplanets (from least to greatest mass and radius) are: 1) rocky planets (like Earth and Venus); 2) Super-Earths; 3) mini-Neptune; 4) ice giants and; 5) gas giants (like Jupiter and Saturn).[98]A habitable exoplanet would have to have a mass between 0.1 and 10 of Earth masses, and a radius between 0.5 and 2.5 of the Earth's radius.[99] About 55 potentially habitable exoplanets have been found as of 2020; they are believed to comprised of one Sub-Terran (Mars-size), 20 Terran (Earth-size), and 34 Super-Terran (Super Earths).[100] As of August 2022, there is no proof of life on Mars, but because Mars has weather, seasons, ice caps, volcanoes, and plate tectonics like Earth, scientists continue to entertain the idea of life on Mars, or at least the fact that there may have been life on Mars, and perhaps a future colonization by humans.[101] In 2018, NASA detected a level of methane on Mars, and proposed that microorganism may have produced the methane.[102]

Question #3: Does Gravity Play a Role in Evolution?

If there were alien lifeforms, we would expect it to show traits of living things like those on Earth, mainly due to our bias and lack of knowledge of life outside of Earth. Some key traits of life on Earth are cellular organization, reproduction, growth, energy processing, homeostasis, and the ability to adapt.[103] These key traits serve to define life on Earth, but the type of life found elsewhere in the cosmos might surprise us in ways that we have yet to imagine and understand. Gravitational biology is the study of how gravity impacts living things. Since the origin of life on Earth, gravity has served as a constant "parameter of confinement" experienced by living things from water, to air, to land, and unchanged for at least the last four billion years.[104] One research study concluded that gravity may be an evolutionary factor to explain why the heart of a tree snake is located significantly closer to its head, making blood flow easier against gravity than the heart in both land and water snakes.[105] When these snakes were centrifuged, it was found that the tree snake has the highest gravity tolerance, the land the intermediate, and the water snake the least.[106] Gravity also serves as the way to support our body and how we move. When you spread your feet wide apart, you have better support and balance. The closer your center of gravity is to the ground, the more supported you are, and the less likely you would fall to the ground. According to the Guinness World Records, the human's height-weight-age parameters may range from Robert Wadlow at 8 ft 11 in (272 cm) tall, weighed 485 lb. (220 kg), and aged 22 to Pauline Musters at 23 in. (58 cm), 3 lb. 5 oz. (1.5 kg), and 19.[107] The heaviest animal is the blue whale at 160 tons (352,739 lb.), and the lightest of all vertebrates is the dwarf goby at 2 mg (14 oz.).[108] Since gravity pulls all living things down, we can understand why plant's roots grow downward (in the same direction as the force of gravity) and stems grow upward (in the direction of the Sun).[109] When plants are grown upside down, gravity will force the roots to twist and turn until they grow downward, and stems will adapt and turn to grow toward the light source.

Experiments have shown that the size of single biological cells is inversely proportional to how strong the gravitational field is acting on the cell.[110] A stronger gravitational field would have cells of smaller sizes. However, in hyper-gravity (> 1g), cell growth eventually decreased and diminished.[111] When an aircraft followed a parabolic flight for 72 hours in hypo-gravity (zero < g < 1), the production of cells reduced.[112] In a NASA study (2013) on the effects of microgravity (1×10^{-6} g), microbes were seen to have adapted to the spaceflight environment with increased growth, unique cellular changes and processes than on Earth, and the ability to survive in the vacuum of outer space.[113] The food-poisoning bacteria called Salmonella Typhimurium became more virulent during a 2015 space shuttle experiment on microgravity.[114]

The effects of gravity on a many-celled organism have been shown to be more drastic than on a single-cell organism. Prior to animals living on land, most lifeforms were small and looked like a worm or a jellyfish, with no skeletal system. When animals evolved to survive on land, methods of locomotion and skeletal systems were formed to counteract the increased force of gravity. In larger animals, gravitational forces have shown to influence blood circulation, muscles, and bone structures. As a person ages, gravity will continue to compress the body and spine resulting in bad posture, damage organs causing them to shift downward, increase weight in a person's mid-section, and may worsen blood circulation and other health issues. Scientists are making the parallels between the effects of microgravity on astronauts and that of aging on Earth; work from Donald Ingber based on his tensegrity theory has shown that "molecules, cells, tissues, organs, and our entire bodies use tensegrity architecture to mechanically stabilize their shape, and to seamlessly integrate structure and function at all size scales."[115]

If there were lifeforms on exoplanets, or Mars, how would gravity impact them? In a lower gravity field like that of Mars, what would be the gravity's parameter of confinement for living things to thrive? On Mars, would alien lifeforms evolve to be bigger or smaller than earthlings? Or have rounder mid-section, flatter feet, or shorter arms to lessen load? What about in a higher gravity field like that of Kepler 22b, a Super Earth with mass 36 times of Earth? Scientists know that astronauts are relatively adaptive to lower gravity and require a long time to recover, but they are less certain as to what would be the maximum gravitational field humans can survive long term. How gravity impacts life and how lifeforms react to different gravitational environments are still mysteries, under speculations, and in need of more research.

Teaching Strategies:

Preparation, Kickoff, Visuals, and Parent Communication

Before the start of the 10 lessons, it is important to establish norms and routines. Doing the following preparation will increase student engagement, excitement, and parental support. 1) Decorate the classroom with a space theme, a space library, an International Space Station as a learning center; even a few signs and posters will generate excitement and anticipation. 2) Establish a science student journal and make subtitle pages: GRAVITY, LAWS, SOLAR SYSTEM, EXOPLANETS, GLOSSARY for easy reference and retrieval. 3) Request an online or in-person interview with an astronaut, astronomer, physicist or biologist to talk about the impact of gravity. *Skype A Scientist* is a free service to match scientists from all over the globe with classrooms. Sign up at https://www.skypeascientist.com/sign-up.html and allow two weeks for a match. Have students brainstorm interview questions. Students can also submit questions (limited to 250 characters) to NASA at https://www.nasa.gov/content/submit-a-question-for-nasa. Use these headings to guide student inquiry: Becoming an Astronaut, Career at NASA, International Space Station, Mars Program, NASA History, and Solar System. 4) Assign solar system topics for individual research and/or experiment about gravity. Send home a parent letter about the unit, and include resources like a NASA webpage for parents to explore with their children at home, https://spaceplace.nasa.gov/menu/parents-and-educators/. NASA has a lot of free printable, fun activities, games, and videos that can be downloaded as classroom and homework assignments. Download a free 17-page activity book titled “Become a NASA Space Place Explorer” at https://spaceplace.nasa.gov/activity-books/en/.

Hands-on Activities and Science Journals

During the unit, kickoff the topic of gravity by focusing student inquiry with the three essential questions, activating prior knowledge and debunking common misconceptions, set up further inquiries and independent research ideas based on student interest, and use hands-on activities, real-life scenarios, videos, anchor charts, and graphic organizers like a KWL chart to make complex concepts more student-friendly. Provide ample opportunities for student talks, active participation, peer-to-peer teaching, team collaborations, individual inquires to engage students beyond lectures and direct instruction. Give students choices, and allow them to make good and bad decisions that may lead to success or failure. For example: Under “Classroom Activities,” I’ve listed 4 different methods to make a scale model of the Solar System to challenge students’ perception of how big our Universe is. *Table 2: Our Solar System* lists both relevant and “less important” data, and students must decide which data are crucial in building any scale model.

Celebrate, Display Student Works, and Post-Assessment

After the unit’s lessons, have a public or private celebration with culminating activities such as student presentations of their learning, informational research and argumentative writing. Assign a gravity concept for each student to become the expert-communicator. It can be as simple as explaining Kepler’s 1st law, and showing a parent, a guest from the community or another student how to draw an ellipse with two push pins, a string, and a pencil. Other possibilities are a bulletin board display, a fun night sky show with hand-held flashlights and/or old projectors (see Van Gogh: The Immersive Experience, a 360º digital art exhibition for ideas), or dress up as your favorite astronaut/scientist, planet, exoplanet, or an alien. Survey student understanding with Post Assessment questions: 1) Do you feel that your knowledge had improved about the topic of gravity? Why or why not? 2) Name three facts that you have learned; 4) Describe your favorite activity; 5) Suggest three ways to improve this learning unit.

Classroom Activities

Below is the scope and sequence of the unit. I have organized the 10 lessons into 5 subgroups. Lesson 1A &1B: What is Gravity? and "Gravity and Me" Experiments. Lesson 2A & 2B: Laws of Gravity and ISS Learning Center. Lesson 3A & 3B: Unit Conversion and Scale Model. Lesson 4A & 4B: Exoplanets and Writing. Lesson 5A & 5B: Check on Progress and Celebration.

1) Fun "Gravity and Me" Experiments

Lesson 1A Objective: Students will generate questions and comments about gravity and its impact on the human body to show what they know and want to know. Begin with the unit's first essential question: Q1) What is gravity and the basic laws it follows? On a large chart paper, write the question on top of a **KWL** three-column graphic organizer: "What We **Know**", "What We **Want** to Know" and "What We **Learn**." Give students two minutes of think time before passing out two posits per students to write a statement/comments/question to pick under "What We Know" and "What We Want to Know." Students may work together or independently. Use teacher's observations to pre-assess what students know. After students post their answers, look for the common misconceptions listed below. **Possible answers:***Gravity can move things. Planets farthest from the Sun has the least gravity. Heavy objects fall faster than lighter objects.* Conclude the lesson with a demonstration of Galileo's Law of Free Fall by dropping an apple, a book, a bag of feathers, a paper clip and/or other objects of various mass from a table to the floor, and ask what happens. Have students Think-Pair-Share. Record student observations on a chart paper. Explain to students that tomorrow (or during the next lesson) they will learn about gravity from three famous male scientists: Galileo, Newton, and Einstein.

Lesson 1B Objective: Students will be introduced to laws about gravity. Review answers to the first essential question from yesterday's KWL graphic organizer written on chart paper. Tell students today they will record their additional observations on their own KWL graphic organizer inside their science journals. Distribute *Table 1: Gravity and Me Experiments* to each student. Teacher will demonstrate one law from each of these scientists: Galileo, Newton, and Einstein with a video and/or an in-person demonstration using resources from this unit. As time permits, give students opportunities to test out some of these ISS activities and gravity experiments in a group or independently during learning centers. Most of the selected activities have a video version and/or require basic items that you, your students and parents can find at home or in the classroom. Have students stapled *Table 1: Gravity and Me Experiments, Table 2: Our Solar System* and *Table 3: Exoplanets* to their science journals to serve as a Table of Content, and reference for later classroom activities. Ask students what did you learn today and have them reflect on their KWL chart under L (What We Learned).

2) International Space Station (ISS) Learning Center

Lesson 2A Objective: Students will perform experiments to understand the basic laws of gravity. Begin this pair of lessons by focusing on the 2nd essential question. Q2) How does gravity affect life and space travel? Possible misconceptions: *Astronauts can fly in space. Zero-gravity means you weight 0 pounds (remember all matter has mass & volume). A black hole has nothing in it.* Set up an ISS learning centers with activities for students to inquire how gravity impact astronauts and space travel. For instance: Have a plastic cup stacking contest to “defy” gravity, visit the website “Phet” https://phet.colorado.edu/en/search?q=gravity for investigate computer-based simulation, or check out this space flight simulation: https://steampeek.hu/?appid=1607560).

Lesson 2B Objective: Students will be introduced to the concepts and experiments of microgravity that the International Space Station and other programs had conducted. A science educational program called *STEM in 30* produces 30 minutes videos by the Smithsonian’s National Air and Space Museum. Visit https://airandspace.si.edu/iss-science and choose one of the following experiments to replicate: 1) *Bone Density with Cereal*; 2) *Puffy Head Bird Legs*; 3) *“Taternauts” and Spacesuits*; 4) *How to Launch a Rocket*; 6) and *Spot the International Space Station in Your Backyard*! In addition, YouTube has an extensive collection of classroom and ISS experiments about microgravity: 1) *NASA Explorers S4 E1: Orbiting Laboratory*; 2) *How Mass and Gravity Work in Space-Classroom Demonstration*; 3) and *Space Station Highlights*. Additional activities for the ISS Learning Center: 1) *Imagine You’re an Astronaut*, www.jpl.nasa.gov/edu/learn/project/imagine-youre-an-astronaut; 2) *NASA Astronaut Talks to Students*, www.youtube.com/watch?v=V1O7XfcXGTI; 3) *International Cooperation*, www.nasa.gov/mission_pages/station/cooperation/index.html; 4) and *STEMonstrations: Newton's First Laws of Motion*, www.youtube.com/watch?v=-luKN6mad5w.

Beside the extensive collection of resources, videos, and free printouts from the NASA’s website (https://nasa.fandom.com/wiki/List_of_NASA_websites), also take advantages of the resources from SETI Institute (search for extraterrestrial intelligence, https://www.seti.org/education) and the other four participating space agencies of the International Space Station, and compare any discrepancies and biases: Roscosmos (Russia, https://en.roscosmos.ru/), JAXA (Japan, https://edu.jaxa.jp/en/), ESA (Europe, https://www.esa.int/kids/en/teachers), and CSA (Canada, https://www.asc-csa.gc.ca/eng/youth-educators/), especially look for videos with astronauts talking to students. Keep issues about the gender, racial, and income disparities as a global forefront for humanity future in your day-to-day discussion of space travel. Make deliberate efforts to select interviews from individual of underrepresented groups and countries.

3) Scale Models of Our Solar System

Lesson 3A Objective: Students will be able to convert different units of measurements using scientific notations, fractions, and decimals. **Discussion:** Astronomers have to work with dimensions and distances that far exceed our everyday experience. If you open a science book about the Solar System, every single picture that you would see will **not be to scale.** Why? The reason is that the distance is too great to represent on a piece of (8 ½ by 11 inches) paper. All the planets would be microscopic, and you will not be able to see any of the planets. The term "terrestrial planets" refers to Mercury, Venus, Earth, and Mars. The term "gas giants" refers to Jupiter, Saturn, Uranus, and Neptune. The International Astronomical Union (IAU) “demoted” Pluto to the status of “dwarf planet” since 2006. Our host star is the Sun. **Math Lesson (Standards 5.MD.A.1):** Explain to students that the numbers needed to construct the Solar System are huge, and scientists use scientific notations to make calculations easier. For example: The distance from the Sun to Earth is 92,960,000 miles (1 AU, an astronomical unit), Earth's mass is 5,972,000,000,000,000,000,000,000 kilograms (kg), and the Sun's mass is 1,989,000,000,000,000,000,000,000,000,000 kg. It is easier to write these numbers as 92.96 million mi, 5.972×10^{24} kg, and 1.989×10^{30} kg. Have students count the number of zeros, and ask "higher order thinking" questions: "Why the number 1.989×10^{30} kg written out in kg would have 27 zeroes, but 30 zeroes if convert to grams (g)? Why would it be correct to say the Sun's mass is 0.333×10^{6} times greater than the Earth's mass? What operation(s) is needed to calculate this comparison? Point out most scientists also work with very small numbers and use scientific notations like these: 8×10^{-4} cm (0.0008 cm) for the average diameter of a red blood cell, the diameter of the COVID-19 virus is ≈ 0.1 µm (one micrometer = 1 µm = 1.0×10^{-6} meters), and the mass of an electron is 9.1096×10^{-31} . Explain to students that when they scale the Solar System, they are mastering their math skills and applying numbers to solve a real-life problem.

Lesson 3B Objective: Students will collaboratively discuss, choose, and make a scale model of our Solar System. **Computer Simulation:** Log into https://gravitysimulator.org/solar-system/the-inner-solar-system (it may take a minute to load) to see a visual simulation of planets rotating around our Sun. Click on the "play" arrow. Select the speed of the rotation by years, months, and days. First, play it with our "Sun" as the rotating reference frame, then change the rotating reference frame to Earth and other planets. Under the menu *Masses*, students can investigate the various effects by changing the Sun into other host stars (such as Kepler-62, and GJ 66 C). **Scale Model-Making:** I've gathered the following solutions to the scale problem for students and teachers to discuss and choose their solution. Use Table 2 and 3 as reference.

Scale Model #1 (watch https://www.youtube.com/watch?v=zR3Igc3Rhfg): Filmmakers Wylie Overstreet and Alex Gorosh built the 1st-ever scaled model in Black Rock Desert, Nevada. Earth was scaled to the size of a marble, and the entire model required 7 miles of empty space.

Scale Model #2: *The Exploratorium* website, https://www.exploratorium.edu/ronh/solar_system/, allow users to enter the Sun's diameter in inches or millimeters, and will automatically "Calculate" the scaled distances for each planet. The site suggested using a roll of toilet paper and scaled the Sun's diameter to 0.4 inch (10 mm). The scaled distance of the entire Solar System can be covered with one roll of toilet paper. Mercury will be about 1½ feet from the Sun, Venus over 2½ feet, Earth over 3½ ft., Mars almost 5½ ft., Jupiter over 18½ ft., Saturn over 34 ft., Uranus over 68½ ft. and Neptune over 107½ ft. A standard roll of toilet paper has about 450 sheets (each sheet about 4.375 inches long) that would make the entire roll about 164 ft. long.

Scale Model #3: Plot the Solar System on Google Map or Google Earth. Have students use city blocks and spherical objects like fruits, seeds, beans, balls and/or balloons to visualize the model. Have students measure the diameters of spherical objects, and place them in size order, and then find the closest real-life spheres to the suggested spheres for each planet. Use 161 meters as one city block (the scaled distance from Sun to Earth) as well as Earth's orbital radius. Start with the Sun (a person standing, 1.5 meters in height) as the center. Mercury (a small bean, 5 mm in diameter) is 62 meters away from the Sun (< ½ of a city block). Remember to draw a circle of < ½ of a city block on your map for Mercury's orbit. Venus (a grape, 13 mm) is 116 meters (< one city block away). Earth (a grape, 14 mm) is 161 meters (one city block). Mars (a large bean, 7 mm) is 245 meters (> 1 ½ of a city blocks away), Jupiter (a large orange, 155 mm) is 838 meters (> 5 city blocks), Saturn (a small orange, 125 mm) is 1538 meters (> 9 ½ city blocks away), Uranus (an apple, 50 mm) is 3093 meters (> 19 city blocks), Neptune (an apple, 49 mm) is 4849 meters (> 30 city blocks), Pluto (a poppy seed, 2.4 mm) is 6372 meters (> 39 ½ city blocks).
https://www.google.com/maps/d/viewer?mid=1eugZcZgb_7KYXsyCc811sWRxgb8&usp=sharing is a sample

Google Map model from the Spring View Middle School, California.

Scale Model #4: Use time instead of distance. Since it takes 8 minutes and 20 seconds or 1 AU for light to traverse the distance from the Sun to the Earth. This unit of time can replace the unit of length which equals to 93 million miles (150 million km). Mercury is 0.39 AU away from the Sun (0.39 multiply by 8 min. 20 sec. is > 3 min.), Venus 0.723 AU (6 min.), Earth 1 AU (8 min. and 20 sec.), Mars 1.524 AU (> 12 min.), Jupiter 5.203 AU (> 40 min.), Saturn 9.539 AU (> 76 min.), Uranus 19.18 AU (152 min.), Neptune 30 AU (240 min.), Pluto 39.53 AU (320 min.).

4) Argumentative Writing: Super Earth v. Mars-Like Earth

Lesson 4A Objective: Students will examine **Table 3: Exoplanet** and compare units in terms of mass, radius, distance from its host Sun, orbital period, and rotation period to evaluate the likelihood of alien lifeforms on each exoplanet. Begin this pair of lessons by focusing on the 3rd essential question. Q3) Does gravity play a role in evolution? Possible misconceptions: *Yes, gravity made human stronger. No, gravity doesn't change how we grow*. **Lesson 4B Objective:** Students will choose an exoplanet, give reasons why it is habitable for humans and write an argument supporting their decision with data evidences. Teacher will model how to write an argument using data from Table 3 and Table 2. Writing Instruction for Students: You are the author of a new Universe with two Earth-Like exoplanets: one more massive (heavier) and one less massive (lighter). If the only variable is mass, where would you choose to live; give at least 3 reasons. If there were alien lifeforms in these exoplanets, what would they look like? Include a drawing of an alien lifeforms and data to support your argument. Start with the following data:

Name of the Earth-like planet you chose: ____.

Mass of the Earth: ____.

Mass of the exoplanet you chose: ____.

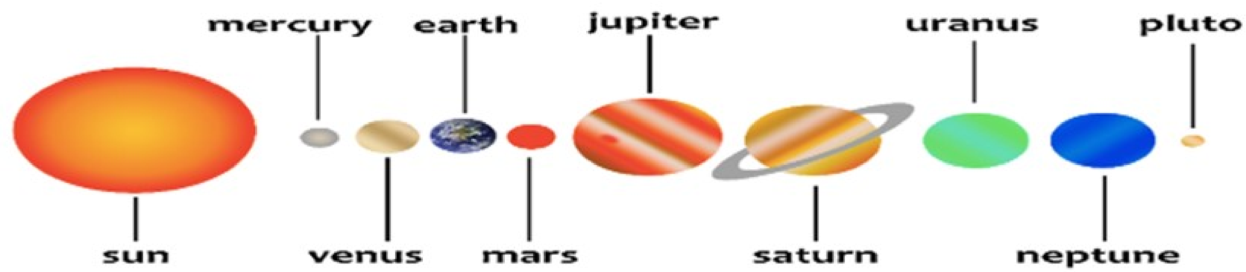
This means that your exoplanet is ________________ times greater OR less massive than Earth.

5) Celebration (See **Teaching Strategies** for More Details): **Lesson 5AObjective:** Allow students time to write their exoplanet arguments with student talks, peer-to-peer support, internet research, and teacher's guidance. Give post-assessment survey. **Lesson 5B Objective:** Discuss as a group how to present what the class has learned about the impact of gravity on life to each other, and other members of the community.

Laws	Explanation	Student's Notes and Drawings	Activities
Galileo's Law of Free Fall $d=1/2gt^2$ (No air resistance)	Bodies fall with the same acceleration, independent of mass where the distance is proportional to the square of the time.		**Dropping objects:** https://whyy.pbslearningmedia.org/resource/nvmm-math-fallingbodies/
Newton's Law of Gravitation $F = G(m_1m_2)/d^2$	any particle of matter attracts any other with a force varying directly as the product of the masses and inversely as the square of the distance btw. them.		**Phet online simulation** https://www.youtube.com/watch?v=2enopo0ysz0
Einstein's Theory of Special Relativity $E = mc^2$	the speed of light (c) and mass (m) can be interchanged with enormous amounts of energy (E).		**Visualization:** https://www.youtube.com/watch?v=C2VMO7pcWhg
Kepler's Laws of Planetary Motion $P^2 = a^3$ Expressed in astronomical units (AU).	1st Law: Each planet moves around the Sun in an elliptic orbit and the center of the Sun is one of the two foci of the ellipse.		**How to draw ellipses:** https://www.youtube.com/watch?v=Et3OdzEGX_w **Laws & Orbits:** https://www.youtube.com/watch?v=6TGCPXhMLtU **Nepture's orbit**: https://www.youtube.com/watch?v=9V8bdL65-3Y
	2nd Law: Orbital speed of a planet increases when near the Sun, and decrease when far from it.		
	3rd Law: The time period of a planet's orbit (P^2) squared is equal to the axis of the orbit (a^3) cubed.		
Newton's Laws of Motion F=ma, W=mg	1st Law: A body at rest will remain at rest; a body in motion will keep moving.		**STEM At Home:** https://www.youtube.com/watch?v=1NPK9420wD4. **Phet simulation:** https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html
	2nd Law: Force is equal to the rate of change of momentum. Force equals mass times acceleration.		
	3rd Law: when two bodies interact, they apply forces that are equal in magnitude and opposite in direction.		
Einstein's Law of General Relativity	The 1915 General Theory of Relativity holds that what we perceive as the force of gravity arises from the curvature of space and time.		**Brian Green's homemade space-time simulator:** https://www.youtube.com/watch?v=uRijc-AN-F0

Table 1: Gravity and Me Experiments. The above chart serves as a teacher and student guide to explanations, formulas, and resources on some basic laws about gravity. Students can use it as a table of

content with quick drawings and note-taking.



Solar System	Earth	Sun	Moon	Mercury	Venus	Mars	Jupiter	Saturn	Uranus	Neptune
Planet, Star or Moon	3rd	Host Star	Earth's Moon	1st	2nd	4th	5th	6th	7th	8th
Gravity's Surface, m/s^2	9.8	274	1.62	3.7	8.87	3.721	24.79	10.44	8.87	11.15
Diameter Km	12,756	1.3927 million	3,478	4,879	12,104	6,756	142,984	120,536	51,118	49,528
Mass $x10^{24}$ kg	5.9722	1,988,500	0.07346	0.3285	4.867	0.639	1,898.13	568.3	86.81	102.4
Density g/cm^3	5.51	1.41	3.34	13.59	5.2	3.9	1.3	0.69	1.27	1.64
Volume km^3	1.08321×10^{12}	1.409×10^{18}	2.1958×10^{10}	6.083×10^{10}	9.2843×10^{11}	1.6318×10^{11}	1.43128×10^{15}	8.2713×10^{14}	6.833×10^{13}	6.254×10^{13}
Escape Velocity km/s	11.2	617.5	2.38	4.25	10.36	5.03	60.20	36.09	21.38	23.56
Rotation on its own axis	1 day or 24 hours	27 days	27.3 days	59 days	243 days	1.03 days	10 hours	11 hours	17 hours	16 hours
Axis Tilt	23.5	7.25	6.7	No tilt	3	25	3.13	26.73	98	28.32
Revolution days or years	365.25 days around Sun	230 million years around Galaxy	29.5 days around Earth	88 days around Sun	224 days around Sun	687 days around Sun	12 years around Sun	29 years around Sun	84 years around Sun	165 years around Sun
Distance from Sun million miles	94	0	0.24 from Earth	35	67	142	484	889	1,790	2,880
Orbital Eccentricity	0.017	*	0.055	0.206	0.007	0.094	0.049	0.052	0.047	0.010
Mean Temperature in °F (°C)	59°F 15°C	more than 10,000°F 5,500 °C	107 °C to minus 153 °C	333°F 167°C	867°F 464°C	Minus 85°F Minus 65°C	Minus 166°F Minus 110°C	Minus 220°F Minus 140°C	Minus 320°F Minus 195°C	Minus 330°F Minus 200°C
Surface Composition	Rocky	Gaseous	Rocky	Rocky	Rocky	Rocky	Gaseous	Gaseous	Gaseous	Gaseous
Rings and Moons	1 moon	NA	NA	zero	zero	2 moons	60 moons & rings	31 moons & rings	27 moons & rings	13 moons & rings
Spacecraft Travel Time from Earth	0	** 19 years	3 days	5 mos.	3 mos.	8 mos.	5 years	7 years	10 years	12 years

Table 2: Our Solar System. This table shows data that I had gathered from NASA and other sources online. Please Note: *The Sun's orbital eccentricity is at this time impossible to determine because it takes the Sun

about 226-million years to complete one orbit around the Milky Way Galaxy.**At this time, we don’t have the technology for a spacecraft to withstand the Sun’s extreme surface temperature (photosphere) at about 5,500 °C (10,000 °F) to travel to the Sun and back. https://solarsystem.nasa.gov/solar-system/sun/in-depth/

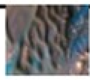
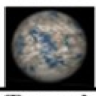
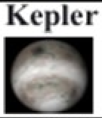
Name of Planets in Our Galaxy	Type: Sub-Earth, Earth-Like, Super Earths	Mass and Radius (in Earth units), Mean Temperature	Host Star Type Distance away from host	Orbital and Rotation Periods
Earth 	Earth	1 Earth mass 1 Earth radius 15 °C (59 °F)	Sun G2V 1AU	365.26 days 23.9 hours
Mars 	Sub-Earth	0.107 Earth mass 0.532 Earth radius minus 65 °C (-85 °F)	Sun G2V 1.52 AU	687 days 24.6 hours
Moon 	Moon not a planet	0.16 Earth mass 0.2725 Earth radius minus 130 °C (-208 °F)	NA (not a planet, but a natural satellite of Earth)	29.5 days 27 days
TRAPPIST-1d 	Sub-Earth Venus-Like, Rocky	0.388 Earth mass 0.78 Earth radius 9.0 °C (48.1 °F)	TRAPPIST M8V 0.02227 AU	4 days 1.51 days
GJ 367 b 	Sub-Earth Mars- and Mercury-Like	0.546 Earth mass 0.718 Earth radius 1,500 °C (2,730 °F)	Gliese 367 M-type 0.0071 AU	7.7 hours Unknown?
TRAPPIST-1e 	Sub-Earth Mars-Like	0.70 Earth mass 0.92 Earth radius minus 27 °C (−17 °F)	TRAPPIST M8V 0.02925 AU	6.1 days Unknown?
Teegarden's Star b 	Earth-Like	≥1.05 Earth mass 1.02 Earth radius 28 °C (82.4 °F)	Teegarden's Star M-type 0.0252 AU	4.9 days Unknown?
Kepler-1649c 	Earth-Like	1.2 Earth mass 1.06 Earth radius minus 39 °C (−38 °F)	Kepler 1649 M-type 0.0649 AU	19.5 days Unknown?
Proxima Centauri b 	Earth-Like	≥1.27 Earth mass ≥1.30 Earth radius minus 11 °C (-71 °F)	Proxima Centauri M-type 0.0485 AU	11.2 days Unknown?
Kepler 22b 	Super Earth	36 Earth mass 2.4 Jupiter radius 15.5 °C (60 °F)	Kepler 22 G-type 0.849AU	289.9 days Unknown?
Gliese 667 C c 	Super Earth	≥3.8 Earth mass ≥1.77 Earth radius 3427 °C (6200 °F)	Gliese 667 M1V, red dwarf 0.125 AU	28.1 days Unknown?
Tau Ceti f 	Super Earth	≥3.93 Earth mass ≥1.81 Earth radius 154.0 °C (309.3 °F)	Tau Ceti G8V 1.334 AU	1.7 years Unknown?
Kepler 452b 	Super Earth	3.29 Earth mass 1.63 Earth radius minus 8 °C (17 °F)	Kepler 421 G-type 1.046 AU	384.8 days Unknown?
LHS 1140 b 	Super Earth	6.38 Earth mass 1.635 Earth radius minus 19 °C (−2 °F)	LHS 1140 M-type 0.0957 AU	24.7 days Unknown?

Table 3: Exoplanets. A short list of exoplanets with habitable zone, possible atmosphere & liquid water.

Earth, Mars and our Moon are included for comparison. Visit NASA's exoplanet catalog at https://exoplanets.nasa.gov/discovery/exoplanet-catalog/ for updates.

Appendix on Implementing District Standards

This unit will incorporate Middle School (5th to 8th grade) Next Generation Science Standards with 5th Grade Math and ELA Common Core Standards. The themes from my District's Science Standards are "Earth's Place in the Universe" and "Forces and Interactions." Students will write an argumentative letter following the 5th Grade ELA Standard. Students will use Table 1, 2 and 3 to convert units of measurement to figure out a manageable scale model of tour Solar System.

Earth's Place in the Universe, MS-ESS1-2: Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. **Motion and Stability (Forces and Interactions), MS-PS2-1:** Motion and Stability (Forces and Interactions):Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. **MS-PS2-2:** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. **MS-PS2-4:** Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. **MS-PS2-5**: Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

CCSS.ELA-LITERACY.W.5.1: Write opinion pieces on topics or texts, supporting a point of view with reasons and information. **CCSS.MATH.CONTENT.5.MD.A.1**: Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.

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