Introduction

Formative Assessment Exemplar - PHYS.1.3

Introduction:

The following formative assessment exemplar was created by a team of Utah educators to be used as a resource in the classroom. It was reviewed for appropriateness by a Bias and Sensitivity/Special Education team and by state science leaders. While no assessment is perfect, it is intended to be used as a formative tool that enables teachers to obtain evidence of student learning, identify gaps in that learning, and adjust instruction for all three dimensions (i.e., Science and Engineering Practices, Crosscutting Concepts, Disciplinary Core Ideas) included in a specific Science and Engineering Education (SEEd) Standard.

In order to fully assess students' understanding of all three dimensions of a SEEd standard, the assessment is written in a format called a cluster. Each cluster starts with a phenomenon, provides a task statement, necessary supporting information, and a sequenced list of questions using the gather, reason, and communicate model (Moulding et al., 2021) as a way to scaffold student sensemaking. The phenomenon used in an assessment exemplar is an analogous phenomenon (one that should not have been taught during instruction) to assess how well students can transfer and apply their learning in a novel situation. The cluster provides an example of the expected rigor of student learning for all three dimensions of a specific standard. In order to serve this purpose, this assessment is NOT INTENDED TO BE USED AS A LESSON FOR STUDENTS.

Because this assessment exemplar is a resource, teachers can choose to use it however they want for formative assessment purposes. It can be adjusted and formatted to fit a teacher's instructional needs. For example, teachers can choose to delete questions, add questions, edit questions, or break the tasks into smaller segments to be given to students over multiple days.

Of note: All formative assessment clusters were revised based on feedback from educators after being utilized in the classroom. During the revision process, each cluster was specifically checked to make sure the phenomena was authentic to the DCI, supporting information was provided for the phenomena, the SEPs, CCCs, and DCIs were appropriate for the learning progressions, the cluster supported student sensemaking through the Gather, Reason, and Communicate instructional model, and the final communication prompt aligned with the cluster phenomena. As inconsistencies were found, revisions were made to support student sensemaking. If other inconsistencies exist that need to be addressed, please email the current Utah State Science Education Specialists with feedback.

General Format:

Each formative assessment exemplar contains the following components:

1. Teacher Facing Information: This provides teachers with the full cluster as well as additional information including the question types, alignment to three dimensions, and answer key. Additionally, an example of a proficient student answer and a proficiency scale for all three dimensions are included to support the evaluation of the last item of the assessment.
2. Students Facing Assessment: This is what the student may see. It is in a form that can be printed or uploaded to a learning platform. (Exception: Questions including simulations will need technology to utilize during assessment.)

Accommodation Considerations:

Teachers should consider possible common ways to provide accommodations for students with disabilities, English language learners, students with diverse needs or students from different cultural backgrounds. For example, these accommodations may include: Providing academic language supports, presenting sentence stems, or reading aloud to students. All students should be allowed access to a dictionary.

References:

Moulding, B., Huff, K., & Van der Veen, W. (2021). *Engaging Students in Science Investigation Using GRC*. Ogden, UT: ELM Tree Publishing.

Teacher Facing Info

Teacher Facing Information

Standard: Phys.1.3

Assessment Format: Printable or Online Format (Does not require students to have online access)

Phenomenon

Landing a device on a celestial body.

When a rover, drone, or robot lands on a celestial body, it will approach with a velocity. This velocity will need to be reduced in order to prevent a crash. The impact force from the collision will destroy the item.

Proficient Student Explanation of Phenomenon:

The most successful landings on Mars combine multiple methods of landing into one protocol. Based on the tables and readings, design constraints are as follows; atmosphere density, gravity and weight of the craft.

Mars' atmosphere is more dense, and it’s gravity is higher. Mars is also dry and dusty with extreme heat and cold. Pluto has less gravity, almost no atmosphere and is icy and extremely cold.

Due to the low density of Pluto’s atmosphere, parachutes would not be a solution. Retrorockets and air bags in combination would best fit the criteria for landing on Pluto. The craft will also be lightweight due to the low gravity here.

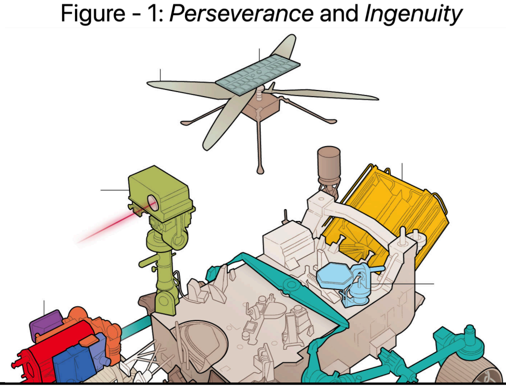
Retrorockets will be used to initially slow the incoming lander to speeds where the airbags (also could use sky crane) would reduce the impact force further, slowing the lander over time to reduce force. Because of the low gravity and air density, retrorockets will be effective in providing the opposing force to slow the incoming lander.

Cluster Task Statement

In the questions that follow, you will evaluate and optimize a design that has the function of minimizing the impact force of a rover landing on Pluto. You will identify the constraints and concerns that result from the differences between the planets, reference Newton’s laws of gravitational force, and predict ways for improving the design.

Supporting Information

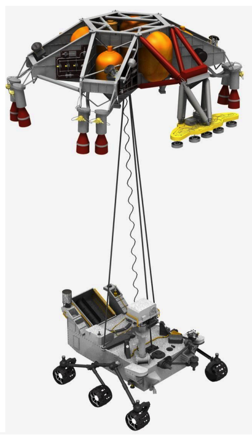
Figure - 1: *Perseverance* and *Ingenuity*



Because of the constraints and challenges of landing a human being on Mars, NASA has instead developed six landing crafts that successfully reached the planet. The most recent, *Perseverance*, landed on Mars on February 18th, 2021. It was a rover type craft that featured an accompanying helicopter named *Ingenuity*. Both are featured in **figure-1**.

These six landing craft were constructed to be compatible for landing only on Mars, a rocky planet with a fluctuating temperature. *Perseverance* was equipped with wheels that were thick, durable, and made of aluminum. The wheels also possessed cleats for traction and curved spokes for springy support. Additionally, it was equipped with a heat shield that could withstand temperatures of 1300°C. The *Viking* used 24 parachutes in order to slow the rover down during descent. The *Mars Pathfinde*r was equipped with three rocket-assisted descent (RAD) motors. A radar system detected its closeness to the surface of the planet and then fired off the rockets to slow down the rover's descent. The *Spirit Rover* had airbags that allowed it to "bounce" into a crater and the *Curiosity* rover was able to use a "sky crane" shown in **figure-2.**

Figure - 2: Sky Crane



Other rovers, such as the *Mars-2* and *Beagle-2* unsuccessfully crashed into Mars and were unrecoverable. Due to a low density atmosphere, the airbags did not deploy on *Beagle-2*. A dust storm caused *Mars-2* to crash into the planet.

Pluto is a celestial body much further away than Mars, yet NASA is ever more determined to land a rover for exploration. On July 14, 2015, NASA's New Horizons spacecraft drifted by Pluto and took the first known photographs of the celestial body. However, the spacecraft was unable to land on its surface. Due to the differences between Earth, Mars, and Pluto, scientists have yet to design a rover that could land on Pluto. The differences between the planets and Pluto are located in **figure-3**.

Figure - 3
Landing Conditions for Select Planets/Bodies

Planet/Body	**Gravitational Acceleration**	**Atmospheric Density**	**Surface Conditions**
Earth	9.81 m/s^2	1013.25 millibars	Rocky, wet, Temperate
Mars	3.71 m/s^2	6.518 millibars	Dry, Dusty, Rocky, Extreme Heat and Cold
Pluto	0.62 m/s^2	0.013 millibars	Small, Icy, Rocky, Extreme Cold

In the questions that follow, you will evaluate and optimize a design that has the function of minimizing the impact force of a rover landing on Pluto. You will identify the constraints and concerns that result from the differences between the planets, reference Newton's laws of gravitational force, and predict ways for improving the design.

Supporting Information and References:

*****Extension material: Reading 2**: Article about design of Mars lander relating atmosphere, gravity and surface conditions to landing design solutions.
https://mars.nasa.gov/mer/mission/technology/edl/

***** Extension material: Reading 3**: Article and video covering surface of Pluto sent by New Horizons.
https://blogs.nasa.gov/pluto/2015/12/24/pluto-through-a-stained-glass-window-a-movie-from-the-ed

ge-of-our-solar-system/

Reading 4: Success and Failure:
Reaching Mars is a hard and unforgiving endeavor, with little room for error. A large proportion of the 50-odd missions launched toward Mars have been lost due to failed components, rocket glitches or grievous errors that sent probes crashing into the Martian surface or missing the planet altogether.

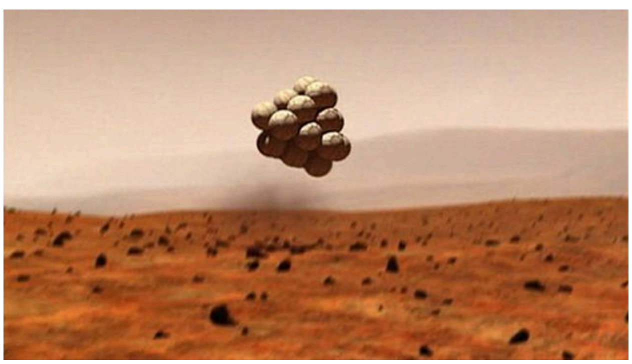
Landing missions are especially tricky due to the long time delay between Mars and Earth communications, the thin Martian atmosphere, and the fact that spacecraft and their components must survive several months in space before making it to the surface. We have been very lucky with many landing missions, but not all of them made them down.
Unsuccessful Landings:

Mars 2, a lander built by the former Soviet Union, has the double-edged distinction of being the first human-built object ever to touch down on the Red Planet. Launched in tandem with its sister craft Mars 3 in 1970, the spherical 1-ton Mars 2 lander was about the size of a kitchen stove and designed to parachute to the Martian surface and use rockets for final braking.

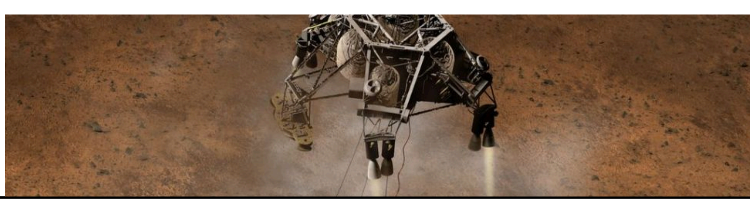
Despite surviving the long trip to Mars — a major feat in itself— the probe crashed into the Martian surface somewhere west of the Hellas basin while a major dust storm churned across the planet.

Shaped like an oversized pocket watch, Beagle 2 hitched a ride to the Red Planet aboard Europe's Mars Express orbiter, but crash landed on the planet rather than bouncing to a stop with airbags. A lower than expected atmospheric density may have caused the probe's parachute and airbags to deploy too late, an investigation later found.

Successful Landings:
The first successful landing on Mars came on July 20, 1976, when NASA's Viking 1 lander touched down in Chryse Planitia (The Plains of Golf). The massive 1,270-lb (576-kilogram) lander dropped from an orbiting mothership to make a three-point landing using a parachute and rocket engine.



The Mars Pathfinder Lander used a parachute and airbags to land on Mars.
The success of Mars Pathfinder and its Sojourner rover led to a larger, bolder Mars landing on Jan. 4, 2004, when NASA's golf cart-sized Spirit rover bounced to a stop inside the broad Gusev Crater.



NASA's flagship Curiosity rover finished a never-before-executed complex landing sequence on Aug. 6, 2012, flawlessly stepping through parachute deployment and a "sky crane" deployment to settle into the surface in Gale Crater. The rover's design (and some of its instruments) have been adapted for the Perseverance rover mission, which successfully landed on Feb. 18, 2021. (adapted from https://www.space.com/10930-mars-landings-red-planet-exploration.html)	
Cluster Questions	
Gather: Cluster Question #1 Question Type: Multiple Select Addresses: SEP: Evaluate design solutions CCC: Structure or function DCI: PS2.A, ETS1.B Answer: The answer is **bold**.	**Item:** Which **two** design criteria were most commonly associated with successful landings on mars? **a. Slowing down the descent** **b. Combining multiple descent methods or procedures** c. Speeding up the descent d. Bouncing multiple times e. Resisting very high temperatures
Gather: Cluster Question #2 Question Type: Multiple Select Addresses: SEP: Evaluate design solutions CCC: Structure or function DCI: ETS1.A, ETS1.B Answer: The answer is **bold**.	Item: A rover that could successfully land on Pluto must be modified to satisfy which **three** conditions: **a. Atmospheric density** b. Wind speed **c. Gravity** **d. Weight of craft** e. Angle of entry
Reason: Cluster Question #3 Question Type: Multiple Choice Addresses: SEP: Evaluate design solutions CCC: Structure or function DCI: ETS1.C Answer: Answer is in **bold**.	Item: Using the *Perseverance* rover as an initial design, which stage of the design process must be completed next to optimize the design for landing on Pluto? a. Test the rover to determine if it is able to float b. Collect data for withstanding temperatures on Pluto **c. Determine the velocity of the rover moving through Pluto's gravitational pull** d. Experiment to determine if the mass of the rover could withstand a dust storm
Reason: Cluster Question #4 Question Type: Matching and short response Addresses: SEP: Evaluate design solutions CCC: Structure or function DCI: PS1.A	Item: Match each one of Newton's laws of motion to a specific action involving the landing sequence of the rover. Include a short rationale for your pairings: **Landing Sequence Action** | **Matching Bays**

<table>
<tr>
<td>Answer:
1- a
2- c
3- b</td>
<td>
<table>
<tr><td>1. The craft is moving downward and will not stop until a force acts on it</td><td>(answer)</td></tr>
<tr><td>2. The craft pushes down on the surface, which pushes back up on the craft</td><td>(answer)</td></tr>
<tr><td>3. While landing, the forces cause an acceleration to slow the craft.</td><td>(answer)</td></tr>
</table>
<table>
<tr><th>Laws</th></tr>
<tr><td>a. Newton’s first law</td></tr>
<tr><td>b. Newton’s second law</td></tr>
<tr><td>c. Newton’s third law</td></tr>
</table>
</td>
</tr>
<tr>
<td>communicate:
Cluster Question #5
Question Type: Ordering with matching bays
Addresses:
SEP: Evaluate design solutions
CCC: Structure or function
DCI: ETS1.C
Answer:
2, 1, 3</td>
<td>Item: “trade-off”
Consider the following design proposals:
1- Air bag only system
2- Rocket and airbag combined system
3- Parachute system
Order each proposal from the highest probability of a successful landing on Pluto to the lowest. Then, explain the reason for your ranking.
<table>
<tr><th>Most Probable</th></tr>
<tr><td>(answer)</td></tr>
<tr><td>(answer)</td></tr>
<tr><td>(answer)</td></tr>
<tr><td>Least Probable</td></tr>
</table>
</td>
</tr>
<tr>
<td>communicate:
Cluster Question #6
Question Type: Long Answer
Addresses:
SEP: Evaluate design solutions</td>
<td>Item:
Type or illustrate a design proposal that is a conceptual model and explanation for a Pluto lander. Include the following components:
1. Landing system that has the function of minimizing the impact force when reaching Pluto’s surface.</td>
</tr>
</table>

CCC: Structure or function DCI: ETS1.A, ETS1.B, PS2.C Answer: Student answers will vary but will meet the 'proficient student explanation' from section 7 below ***this can be made into an extension by expanding it to a project which could be anywhere from days to weeks	2. Label all landing system parts 3. Describe the step-by-step stages/phases of landing 4. Rationale for each stage and system 5. Specific reference to data and concepts in the readings

Proficiency Scale

Proficient Student Explanation:
Students will produce a model with more than 1 type of landing system present, with components clearly labeled. Student's rationale for use of systems incorporates data and ideas from more than 3 of the supplemental materials and provides evidence of changes to a rover design which would be effective in landing on Pluto. Student's answer incorporates data and compares the planets as support for the proposed design.

Level 1 - Emerging	Level 2 - Partially Proficient	Level 3 - Proficient	Level 4 - Extending
SEP: Does not meet the minimum standard to receive a 2.	**SEP:** Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	**SEP:** Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations.	**SEP:** Extends beyond proficient in any way.
CCC:	**CCC:** Structures can be	**CCC:** Investigating or designing	**CCC:**

Does not meet the minimum standard to receive a 2.	designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used	new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.	Extends beyond proficient in any way.
DCI: Does not meet the minimum standard to receive a 2.	**DCI:** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.	**DCI:** Newton's second law accurately predicts changes in the motion of macroscopic objects.	**DCI:** Extends beyond proficient in any way.

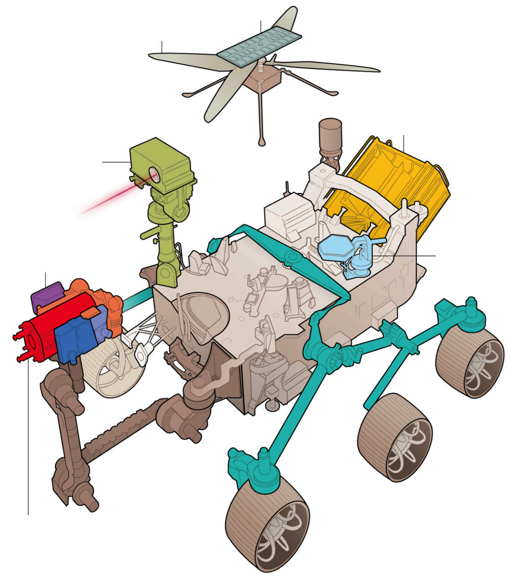
(Student Facing Format on following page)

Student Assessment

Name: ____ Date: ________

Stimulus

Figure - 1: *Perseverance* and *Ingenuity*



Because of the constraints and challenges of landing a human being on Mars, NASA has instead developed six landing crafts that successfully reached the planet. The most recent, *Perseverance*, landed on Mars on February 18th, 2021. It was a rover type craft that featured an accompanying helicopter named *Ingenuity*. Both are featured in **figure-1**.

These six landing craft were constructed to be compatible for landing only on Mars, a rocky planet with a fluctuating temperature. *Perseverance* was equipped with wheels that were thick, durable, and made of aluminum. The wheels also possessed cleats for traction and curved spokes for springy support. Additionally, it was equipped with a heat shield that could withstand temperatures of 1300°C. The *Viking* used 24 parachutes in order to slow the rover down during descent. The *Mars Pathfinder* was equipped with three rocket-assisted descent (RAD) motors. A radar system detected its closeness to the surface of the planet and then fired off the rockets to slow down the rover's descent. The *Spirit Rover* had airbags that allowed it to "bounce" into a crater and the *Curiosity* rover was able to use a "sky crane" shown in **figure-2.**

Figure - 2: Sky Crane

Other rovers, such as the *Mars-2* and *Beagle-2* unsuccessfully crashed into Mars and were unrecoverable. Due to a low density atmosphere, the airbags did not deploy on *Beagle-2*. A dust storm caused *Mars-2* to crash into the planet.

Pluto is a celestial body much further away than Mars, yet NASA is ever more determined to land a rover for exploration. On July 14, 2015, NASA's New Horizons spacecraft drifted by Pluto and took the first known photographs of the celestial body. However, the spacecraft was unable to land on its surface. Due to the differences between Earth, Mars, and Pluto, scientists have yet to design a rover that could land on Pluto. The differences between the planets and Pluto are located in **figure-3**.

Figure - 3
Landing Conditions for Select Planets/Bodies

Planet/Body	**Gravitational Acceleration**	**Atmospheric Density**	**Surface Conditions**
Earth	$9.81\ m/s^2$	1013.25 millibars	Rocky, wet, Temperate
Mars	$3.71\ m/s^2$	6.518 millibars	Dry, Dusty, Rocky, Extreme Heat and Cold
Pluto	$0.62\ m/s^2$	0.013 millibars	Small, Icy, Rocky, Extreme Cold

Success and Failure:

Reaching Mars is a hard and unforgiving endeavor, with little room for error. A large proportion of the 50-odd missions launched toward Mars have been lost due to failed components, rocket glitches or grievous errors that sent probes crashing into the Martian surface or missing the planet altogether.

Landing missions are especially tricky due to the long time delay between Mars and Earth communications, the thin Martian atmosphere, and the fact that spacecraft and their components must survive several months in space before making it to the surface. We have been very lucky with many landing missions, but not all of them made them down.

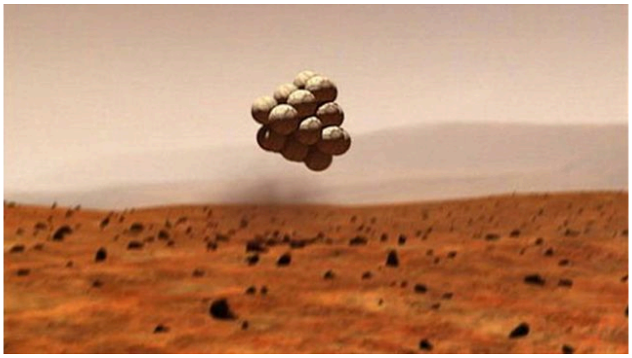
Unsuccessful Landings:

Mars 2, a lander built by the former Soviet Union, has the double-edged distinction of being the first human-built object ever to touch down on the Red Planet. Launched in tandem with its sister craft Mars 3 in 1970, the spherical 1-ton Mars 2 lander was about the size of a kitchen stove and designed to parachute to the Martian surface and use rockets for final braking.

Despite surviving the long trip to Mars — a major feat in itself— the probe crashed into the Martian surface somewhere west of the Hellas basin while a major dust storm churned across the planet.

Shaped like an oversized pocket watch, Beagle 2 hitched a ride to the Red Planet aboard Europe's Mars Express orbiter, but crash landed on the planet rather than bouncing to a stop with airbags. A lower than expected atmospheric density may have caused the probe's parachute and airbags to deploy too late, an investigation later found.

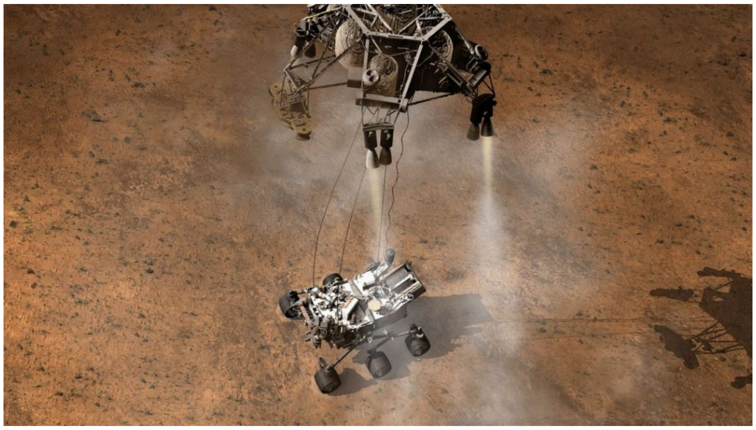
Successful Landings:



The first successful landing on Mars came on July 20, 1976, when NASA's Viking 1 lander touched down in Chryse Planitia (The Plains of Golf). The massive 1,270-lb (576-kilogram) lander dropped from an orbiting mothership to make a three-point landing using a parachute and rocket engine.

The Mars Pathfinder Lander used a parachute and airbags to land on Mars.

The success of Mars Pathfinder and its Sojourner rover led to a larger, bolder Mars landing on Jan. 4, 2004, when NASA's golf cart-sized Spirit rover bounced to a stop inside the broad Gusev Crater.



NASA's flagship Curiosity rover finished a never-before-executed complex landing sequence on Aug. 6, 2012, flawlessly stepping through parachute deployment and a "sky crane" deployment to settle into the surface in Gale Crater. The rover's design (and some of its instruments) have been adapted for the Perseverance rover mission, which is expected to land on Feb. 18, 2021.

Your Task

In the questions that follow, you will evaluate and optimize a design that has the function of minimizing the impact force of a rover landing on Pluto. You will identify the constraints and concerns that result from the differences between the planets, reference Newton's laws of gravitational force, and predict ways for improving the design.

Question 1

Which **two** design criteria were most commonly associated with successful landings on mars? (Select all that apply.)

- ☐ A. Slowing down the descent
- ☐ B. Combining multiple descent methods or procedures
- ☐ C. Speeding up the descent
- ☐ D. Bouncing multiple times
- ☐ E. Resisting very high temperatures

Question 2

A rover that could successfully land on Pluto must be modified to satisfy which **three** conditions: (Select all that apply.)

- ☐ A. Atmospheric density
- ☐ B. Wind speed
- ☐ C. Gravity
- ☐ D. Weight of craft
- ☐ E. Angle of entry

Question 3

Using the *Perseverance* rover as an initial design, which stage of the design process must be completed next to optimize the design for landing on Pluto?

a. Test the rover to determine if it is able to float
b. Collect data for withstanding temperatures on Pluto
c. Determine the velocity of the rover moving through Pluto's gravitational pull
d. Experiment to determine if the mass of the rover could withstand a dust storm

Question 4

Match each one of Newton's laws of motion to a specific action involving the landing sequence of the rover. Include a short rationale for your pairings:

Landing Sequence Action	Answer	Rationale
1. The craft is moving downward and will not stop til a force acts on it		
2. The craft pushes down on the surface, which pushes back up on the craft		
3. While landing, the forces cause an acceleration to slow the craft.		

Answer Choices Newton's Laws
a. Newton's first law
b. Newton's second law
c. Newton's third law

Question 5

Consider the following design proposals:

1- Air bag only system
2- Rocket and airbag combined system
3- Parachute system

Order each proposal from the highest probability of a successful landing on Pluto to the lowest. Then, explain the reason for your ranking.

Most Probable
Least Probable

Reasoning:

Question 6

Type or illustrate a design proposal that is a conceptual model and explanation for a Pluto lander. Include the following components:

1. Landing system that has the function of minimizing the impact force when reaching Pluto's surface.
2. Label all landing system parts
3. Describe the step-by-step stages/phases of landing
4. Rationale for each stage and system
5. Specific reference to data and concepts in the readings