Project 3: Mission to Mars

Stage 1 - Desired Results

Overview:
In the 3rd project, students are in role as **NASA Entry, Descent, and Landing (EDL) engineers** tasked with answering the question, ***"How can you successfully land a rover on Mars?"*** EDL engineers are responsible for designing the entry, descent, and landing of rovers that carry delicate instruments to Mars. Since the 1970s, NASA has worked to land spacecraft on the surface of Mars, succeeding only 6 times. The ultimate goal is to successfully land humans on Mars, but this significantly increases the mass of rovers and cannot be supported by existing EDL systems. Thus, in this project, students work to maximize the amount of mass the rover can carry and still safely land a crew on Mars. Since Mars is so far away and materials are expensive, EDL engineers first prove that their concepts work on paper and then build prototypes to test on Earth. While Earth's atmosphere isn't quite like Mars', these experiments are the only way for EDL engineers to get a sense of how their device works and what they may need to change in order to successfully land on Mars. To simulate what an EDL engineer does, students will design a rover frame, airbag, and parachutes to safely drop a rover from a height of at least 5 meters, analyzing the terminal velocity and energy conversions with the goal of landing the rover so that the crew and rover survive impact. At the end of the project, students will use NASA's customary reporting procedure and prepare a "Verification & Validation" (V&V) report for NASA. V&V reports are essential for progress at NASA because they both document features of successful systems and target the causes of failures. This project allows students agency to make multiple decisions to build their landing systems in an efficient and creative way, helping support the course driving question, "How can we use physics to creatively solve problems and help us understand our world?"

Project Tasks:
Task 1, *Research Mars Landings:* Students study NASA's previous Mars missions.
Task 2, *Parachute Design*: Students design a build a parachute for their landing system.
Task 3, *Airbag Design*: Students move to the airbag to ensure their crew can land safely on the surface of Mars.
Task 4, *Energy Analysis*: Students explore heat and energy in order to make recommendations for a heat shield that will protect the lander upon entry.
Task 5, *Qualification Testing & Final V& V Report*: Students do a final drop and report on their findings in a NASA Validation & Verification, or V&V, report.

Estimated Project Length: 4 weeks

<table>
<tr><td rowspan="4">ESTABLISHED GOALS

AP Essential Knowledge
3.A.1 An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
3.B.1 If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
3.B.2 Free-body diagrams are useful tools for</td><td colspan="2">Transfer</td></tr>
<tr><td colspan="2">Students will be able to independently use their learning to…
Understand the factors that affect impact force, including impulse and change in momentum
Understand various energies and the factors that affect them
Apply physics understanding in the context of a real-world problem
Articulate, in writing, their understanding of physics and the role of learning from failure in physics</td></tr>
<tr><td colspan="2">Meaning</td></tr>
<tr><td>UNDERSTANDINGS
Students will understand that…</td><td>ESSENTIAL QUESTIONS
How can you successfully land a rover on Mars?</td></tr>
</table>

visualizing forces being exerted on a single object and writing the equations that represent a physical situation. 3.D.2 The change in momentum of an object occurs over a time interval. 4.A.1 The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. 4.A.2 The acceleration is equal to the rate of change of velocity with time, and the velocity is equal to the rate of change of position with time. 4.A.3 Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system. 4.C.1 The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy. 5.B.1 Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects. 5.B.2 A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. 5.B.3 A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. 5.B.4 The Internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. 5.B.5 Energy can be transferred by an external	Students will understand the relationships between an objects' mass, the forces being applied to the object (i.e. air resistance and impact force), and the time over which those forces are applied. This includes understanding that more force is needed in order to bring an object to rest in a short period of time (Impulse-Momentum Theorem). Students will understand that in order to make the rover land safely they should reduce the impact force by increasing the impact time. Students should recognize this concept as impulse. Students will understand that mass and velocity are the only two factors that determine an object's kinetic energy. Students will understand that work changes the kinetic energy of an object. In order to change an object's energy, a force must be applied on the object over a distance (Work-Energy Theorem). Students will understand that the only factors that affect gravitational energy are mass and height. Students should also recognize that the gravitational energy is only present for a system that contains both the lander and planet. Students will understand when the mechanical energy for a system is conserved. Students should recognize that external forces acting on the system changes the total mechanical energy. Students will understand the relationship	

force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. NGSS Practices 1-8 AP Science Practices 1-7	between work and gravitational energy (Work-Energy Theorem). Students will understand the relationship between conservation of energy and forces (Work-Energy Theorem). Students will understand the relationship between work and the direction of the force, as well as other sign conventions of work done on or by the system. Students will understand relationship between power and energy.	
	Acquisition	
	Students will know… Students will know that a graph becomes linear as it reaches terminal velocity, and that the acceleration eventually reaches zero. Students will know that as cross sectional area increases an object will have a slower terminal velocity. Students will know that the greater the weight of an object the greater the terminal velocity. Students will know that the direction of the force and motion of the object are related to the change in energy of the object. Students will know the definition of power and recognize that power represents the rate of energy change. Students will know the definitions of terminal	*Students will be skilled at…* Students will be able to graph and interpret a velocity/time graph for an object falling and reaching terminal velocity. Students will be able to draw free body diagrams for object's falling in the presence of air resistance. This includes: objects in free fall, objects approaching the terminal velocity, objects falling at terminal velocity, and objects falling faster than the terminal velocity. Students will be able to draw free body diagrams depicting that a greater force of air resistance is required to balance out the greater weight of the object. Students will be able to effectively communicate parachute design, experimental design, and findings.

	velocity, air resistance, impulse, conservation of energy, mechanical energy, kinetic energy, and gravitational energy. Students will know that impulse relates to an object's change in velocity and mass (Impulse-Momentum Theorem).	Students will be able to calculate the gravitational potential energy of a systems using information from representations of that system. Students will be able to apply the definition of power and recognizing that power represents the rate of energy change to solving problems involving energy and time. Students will be able to use evidence from testing the landing system to clearly and effectively communicate and analyze successes and failures.

Stage 2 - Evidence

Assessment Evidence

PERFORMANCE TASK(S): Verification & Validation (V&V) Report

Throughout the project, students work towards preparing a "Verification & Validation" (V&V) report for NASA colleagues. V&V reports are NASA's customary reporting procedure and essential for progress at the agency because they both document features of successful systems and target the causes of failures. The report includes a detailed description and justification of team's airbag and parachute designs. Team describe their investigations, report findings, and make recommendations for a heat shield to protect the rover upon entry. Should the team experience an unsuccessful landing, they must describe what can be learned from the failure. At NASA, "failures" are just as important as successes in determining the future of the work.

Verification & Validation Report Criteria

- FORMAT: Sections are in order and the paper has an appropriate flow to it. Subheadings are also used effectively to allow easy finding of key information.
- TITLE & ABSTRACT: Includes a descriptive title, clear summary of the report, and a rationale for why the project and tests was performed.
- INTRODUCTION: Correctly outlines all the background information including: terminal velocity, impulse, kinetic energy, and gravitational potential energy.
- AIRBAG & PARACHUTE DESIGN: Description of both the airbag and parachute design. A clear scientific justification for their design.
- METHODOLOGY: Detailed procedures of how the parachute and airbag were tested, including what data was collected.
- FINDINGS: Values for both terminal velocity and max change in velocity, and an explanation of what these values mean. Sample calculations for both.
- ENERGY ANALYSIS: There are almost no mistakes in describing energy transformations while the lander falls. Clearly describes 3-4 similarities and differences between the Mars EDL and the egg drop.
- CONCLUSION: Clearly describes the observations from the egg drop, including the results of the test.

ADDITIONAL SUMMATIVE ASSESSMENT(S): Final project exam

Students demonstrate understanding of physics concepts by answering AP multiple choice & free response questions. Specifically, students are assessed on:

- Air resistance
- Motion Graphs
- Free Body Diagrams
- Work
- Kinetic energy
- Gravitational energy
- Conservation of energy
- Impulse
- Terminal Velocity

Evaluative Criteria
- Exam answer key

FORMATIVE ASSESSMENT(S): Formative assessment moments are marked as "Teacher Checks" (Embedded in each lesson)
- Generate free body diagrams to depict air resistance
- Determine the factors affecting terminal velocity
- Determine the relationship between impulse and change in velocity*
- Determine the formula for kinetic energy from a graph
- Derive the equation for gravitational energy
- Understand conservation of energy and its relationship to the system
- Accurately represent energy in FBDs
- Distinguish between power and energy
- Gather and analyze evidence from testing
- Articulate analysis of testing in writing

Evaluative Criteria:
- Sample project logs that model accurate student work.
- Teacher Checks that contain guidance for teachers to understand a) where students often struggle, b) how to help students develop their conceptual understanding, and c) what to look for in a given activity.

*Pre/post investigation elicitation questions are designed to surface students' existing ideas about core concepts and then, after the investigation, to refine those ideas.

Stage 3 – Learning Plan

Task 1: Research Mars Landings

In Task 1, students take on the role of EDL (Entry Descent Landing) Engineers, tackling the challenge of helping NASA get humans safely to Mars by designing and testing a model of a landing system that can support a crew to land safely.

Lesson 1: **Project Introduction**

Students get an overview of the project, learn about their role, the project task, and the final V&V report they will need to produce. As a class, they explore the work of EDL Engineers and the challenges of landing humans safely on Mars.

Lesson 2: Case Studies & Lander Design
Students reflect on the constraints of landing a rover on Mars and explore the successes and failures of previous NASA Mars missions. Then, teams draw on what they just learned to build their landers. They will use their landers in subsequent investigations throughout the project.

Task 2: Parachute Design
In Task 2, students think about how they can slow down their lander as it descends to the surface of Mars. They explore terminal velocity and air resistance and then use what they learn to design and test parachutes for their rover. At the end of the task, each group reports out on their design and findings by drafting a section of their final V&V Report. NASA engineers use V&V reports to communicate findings as well as test the theory behind their designs.

Lesson 1: **Air Resistance & Terminal Velocity**
To think about how to initially slow down the lander, modeling the first stages of an EDL human landing on Mars, students participate in an investigation to learn about air resistance and terminal velocity in order to understand how the parachute will help slow down the lander.

Progress Monitoring:
Teacher Check #1: Check the students' graph. They should see a graph that becomes more linear as the coffee filter falls. If their graph is incorrect, they need to retake their data or it will lead to misunderstandings in the remainder of the investigation.
Teacher Check #2: Check the students' FBD diagrams. Students often have the misconception that the force of gravity is greater than the air resistance when the object has reached terminal velocity.
Teacher Check #3: Check the final FBD for the parachuting opening. Many students will draw this diagram incorrectly. Make sure they have shown that the force of air resistance can be greater than the weight when the object is slowing down.

Lesson 2: **What Affects Terminal Velocity?**
Understanding the factors that affect terminal velocity will help students design parachutes that will keep their rovers safe. In this lesson, students apply what they learned to design, build, and test airbags to protect the rover's passengers (eggs), conducting an investigation on their designed rovers, using LoggerPro to calculate impulse, acceleration, and Δv.

Progress Monitoring:
Teacher Check #1: Focus on the final questions comparing landing on Earth to landing on Mars. This line of questions is looking to push the students understanding of air resistance and terminal velocity. Students should recognize that the atmosphere on Mars is thinner and therefore results in higher terminal velocities.

Lesson 3: NASA V&V Report
With a focus on communicating what they have learned and how that influenced the design of their parachutes, students preview and practice writing a Verification & Validation (V&V) Report, the type of report that NASA scientists and engineers use to communicate findings of their tests as well as the theory behind their designs. Students will preview the rubric and a sample V&V report and then begin writing the Introduction and Parachute Design sections of their V&V Report.

Progress Monitoring:

Self & Peer Assessment: As students draft the parachute section of their V&V report, they are encouraged to use the rubric to check their own work and to provide feedback to their peers.

Task 3: Airbag Design

In Task 3, students consider the function of an airbag in slowing down the rover enough to ensure a safe landing. Students explore change in velocity and are introduced to the looped concept of **impulse**, which they will revisit in *Crash Scene Investigation,* to figure out how to design an airbag that will keep their lander from colliding with the surface and injuring the crew or system. At the end of this task, students communicate their airbag design, tests, and findings in their V&V report.

Lesson 1: Impulse

Students have figured out how to slow their rover down, but now need to consider how to protect the lander and crew upon impact. To begin, students engage in an elicitation question to surface their ideas about the relationship between force and change in velocity. They then conduct an investigation in which they determine the relationship between force, time, change in velocity, and mass, thereby building an understanding of impulse. Finally, students begin to brainstorm airbag design using what they learned from the lesson.

Progress Monitoring:

Teacher Check #1: Check to make sure that students recognize the pattern between force and change in time. Students might struggle to determine which object came to rest. Remind to check the change in velocity and compare to the object's original speed.

Teacher Check #2: It is important that students recognize that the area under the force time graph represents the impulse of the object.

Lesson 2: Crumple Zone

Students are now ready to design, build, and test their airbags. They build three bumpers for their rovers, graphing and analyzing data for each addition. Groups use the shape of the graphs and their calculations to evaluate their airbag designs for optimal survivability. Like Task 2, Lesson 3, students work on communicating what they have learned and how that influenced the design of their parachutes, writing the Airbag Design portion of their Verification & Validation (V&V) Report.

Progress Monitoring:

Teacher Check #1: Students should be able to use the force/time graph to determine the impulse and impact force. Check to make sure that students were able to correctly calculate the survivability of their egg.

Task 4: Proving it Works – Energy Analysis

In Task 4, students consider how to protect their lander from burning up as it descends to the surface of Mars. While students do not build a heat shield in this project, they must, as part of their V&V report, make specific recommendations for the heat shield. To do this, they revisit kinetic energy, and learn about gravitational potential energy, conservation of energy, and the work-energy theorem, conducting a series of calculation as they look at the change in energy and work done on the rover as it descends. At the end of this task, students add their heat shield recommendations to their V&V report.

Lesson 1: Work & Kinetic Energy

Students begin Task 4 thinking about what information NASA needs to know to design and develop materials for the heat shield for the rovers. To do so, they watch a video from a heat shield engineer talk about NASA's latest spacecraft, Orion, which plan to send to Mars in 2017. Students then discuss their background knowledge and ideas on work & kinetic energy and conduct an investigation focused on using work from the force of gravity as well as the velocity at impact to graph and derive an equation for the kinetic energy of an object.

Progress Monitoring:
Teacher Check #1: Make sure that the students have derived the correct formula for kinetic energy from the graph. Most students will find this challenging.

Lesson 2: Gravitational Energy
Students continue their exploration of energies they need in order to calculate the energy that builds up on the heat shield, focusing in this lesson on gravitational potential energy. They engage in an investigation in which they derive the formula for gravitational potential energy and develop an understanding of the relationship between gravitational potential energy, height, and mass.

Progress Monitoring:
Teacher Check #1: Check to make sure that students have correctly derived the formula for gravitational energy. Review their answers to the systems questions (11 and 12). Students should indicate that the system only has gravitational energy when the planet is included.

Lesson 3: Conservation of Energy
In Lesson 3, students continue their exploration of energy to answer the question, how much energy builds on up on the heat shield? Students conduct an investigation in order to understand conservation of energy so they can calculate the energy that builds up on the heat shield. To get a sense of the difference in the amount of energy involved with rovers on Earth and the amount of energy landing on Mars, students do a comparison between their rover and the Mars Curiosity Rover.

Progress Monitoring:
Investigation 7 - Conservation of Energy
Teacher Check #1: It is important that student recognize how the conservation of energy is related to a system. Make sure the check their answers to the last few questions to see if the students understand how changing the objects in the system changes the way we think about what types of energies are present.

Curiosity Energy Analysis
Teacher Check #1: There are lots of different things that a teacher could look at here. The most challenging questions for the students will likely involve the FBDs. Check to make sure they are drawn correctly; did students draw the force the correct lengths so that the net force results in the correct direction of the acceleration.

Lesson 4: Effect of Wind
In Lesson 4, students seek to answer the question: What if there was wind at the time of the landing – would that affect the energy that builds up? How? To answer the question, students watch a video about weather on Mars and then, in groups, students work through an investigation to see a pattern of how the direction of the force affects the work done on the rover. One way to debrief the investigation is having students create posters to explain how wind affects the energy built up on the heat shield and then have the class do a gallery walk to provide feedback on the explanation.

Progress Monitoring:

Teacher Check #1: Check the FBD diagrams of the students. Students often struggle to draw FBD for objects traveling at a constant speed.

Teacher Check #2: Students should recognize that the area under a force/displacement graph represents work. Student might struggle with the rules relating the direction of force and change in kinetic energy.

Lesson 5: Power

Heat shields are rated on something called power. The EDL team communicates with the heat shield team the specifications that the heat shield will need. To determine those specifications, students engage in a reading investigation to learn about power. Then, like Tasks 2 and 3, students work on communicating what they have learned about energy by writing the Energy Analysis portion of their Verification & Validation (V&V) Report.

Progress Monitoring:

Teacher Check #1: Students often confuse power with energy. Make sure they understand the distinction between the two and how they are both related to work. They should be able to determine the power dissipated by the lander as it falls.

Task 5: Qualification Testing & Final V&V Report

In Task 5, students complete final modifications to their lander, parachutes, and airbag and then test their system with a final drop, gathering data on the time of the descent and the survival of the crew. Groups reflect on what they learned from their successes and failures and then finalize their V&V report.

Lesson 1: Qualification Testing

In this lesson, students prepare their rovers for Qualification Testing, test their rovers, and then finalize their V&V reports. After some initial time where students can make and record revisions to their rovers, they test their rovers by adding eggs and dropping the rovers. During the drops, students time their rover's descent and then check for "survivors". After all the rovers have been tested, the class compares results. Then, using the rubric and V&V model, students complete the Conclusion section of the V&V Report.

Lesson 2: Final Exam

To demonstrate students' understanding of key concepts, they will take a final exam, created to mirror AP test and contextualized PBL questions. In class, students review their exam answers.

Summary of Learning

- Air resistance
- Motion Graphs
- Free Body Diagrams
- Work
- Kinetic energy
- Gravitational energy
- Conservation of energy
- Impulse
- Terminal Velocity
- Science report writing

• Cooperative group work • Practice AP questions

Course Concepts

+ Foundational Concepts: These concepts "carry forward" through the course. Students learn them in one project and then are expected to continue to apply that knowledge and formulas to subsequent relevant projects.

% Looped Concepts: Looped concepts are different from foundational concepts because student learn different facets of the concept in different projects. This means that students will not explore the topic in its entirety but instead will learn some aspects in one project and then other aspects in a later project. In this course, it is important that students need to know the physics content to meet the project challenge. That means it may not be a "good fit" to instruct on all aspects of a concept in a given project. When students return to the concept, the teacher explicitly links what students learned previously to the new context. The second time a concept is encountered, it is expected that students gain a deeper and more nuanced understanding.

@ Discrete Concepts: These concepts only appear in one project. Students learn the entirety of the AP objectives and apply them in the context of one project.

Physics Concepts		Reel Physics	When in Rome	Mission to Mars	Sticks & Stones	CSI	Planet Hunters	Art in Motion
Kinematics	1D Motion	+	+	+	+	+	+	+
Dynamics	Newton's Laws		+	+	+	+	+	+
	Descriptions of Motion	+	+	+		+	+	+
	Motion Graphs	+	+	+	+	+	+	+
	Free Body Diagrams		+	+	+	+	+	+
Linear Momentum	Impulse			%		%		
Energy	Work			+	+	+	+	+
	Kinetic Energy			+	+	+	+	+

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Physics Concepts		**Reel Physics**	**When in Rome**	**Mission to Mars**	**Sticks & Stones**	**CSI**	**Planet Hunters**	**Art in Motion**
Energy cont.	Conservation of Energy			**+**	**+**	**+**	**+**	**+**
	Gravitational Energy			**+**			**+**	**+**