National Aeronautics and Space Administration

Marsbound! Mission to the Red Planet

Grades: 6-12 **Prep Time:** ~1 hour **Lesson Time:** 3 45-minute sessions

WHAT STUDENTS DO: Design a Mission to Mars.

Curious about how engineers design a Mars mission? In this fun, interactive card game, students experience the fundamentals of the engineering design process, with a hands-on, critical-thinking, authentic approach. Using collaboration and problem-solving skills, they develop a mission that meets constraints (budget, mass, power) and criteria (significant science return). This activity can introduce many activities in technology education, including robotics and rocketry. In this collection, it deepens skills from Lesson 6 and builds them for Lesson 12.

NRC CORE & COMPONENT QUESTIONS

HOW DO ENGINEERS SOLVE PROBLEMS?

NRC Core Question: ETS1: Engineering Design

What Is a Design for? What are the criteria and constraints of a successful solution?

NRC ETS1.A: Defining & Delimiting an Engineering Problem

What Is the Process for Developing Potential Design Solutions?

NRC ETS1.B: Developing Possible Solutions

INSTRUCTIONAL OBJECTIVES

Students will be able

IO1: **to design** a technological solution (mission) by making tradeoffs within constraints

See Section 4.0 and Teacher Guide at the end of this lesson for details on Instructional Objective(s), Learning Outcomes, Standards, & and Rubrics.

1.0 About This Activity

Mars lessons leverage *A Taxonomy for Learning, Teaching, and Assessing* by Anderson and Krathwohl (2001) (see *Section 4* and *Teacher Guide* at the end of this document). This taxonomy provides a framework to help organize and align learning objectives, activities, and assessments. The taxonomy has two dimensions. The first dimension, cognitive process, provides categories for classifying lesson objectives along a continuum, at increasingly higher levels of thinking; these verbs allow educators to align their instructional objectives and assessments of learning outcomes to an appropriate level in the framework in order to build and support student cognitive processes. The second dimension, knowledge, allows educators to place objectives along a scale from concrete to abstract. By employing Anderson and Krathwohl's (2001) taxonomy, educators can better understand the construction of instructional objectives and learning outcomes in terms of the types of student knowledge and cognitive processes they intend to support. All activities provide a mapping to this taxonomy in the Teacher Guide (at the end of this lesson), which carries additional educator resources. Combined with the aforementioned taxonomy, the lesson design also draws upon Miller, Linn, and Gronlund's (2009) methods for (a) constructing a general, overarching, instructional objective with specific, supporting, and measurable learning outcomes that help assure the instructional objective is met, and (b) appropriately assessing student performance in the intended learning-outcome areas through rubrics and other measures. Construction of rubrics also draws upon Lanz's (2004) guidance, designed to measure science achievement.

How Students Learn: Science in the Classroom (Donovan & Bransford, 2005) advocates the use of a research-based instructional model for improving students' grasp of central science concepts. Based on conceptual-change theory in science education, the 5E Instructional Model (BSCS, 2006) includes five steps for teaching and learning: Engage, Explore, Explain, Elaborate, and Evaluate. The Engage stage is used like a traditional warm-up to pique student curiosity, interest, and other motivation-related behaviors and to assess students' prior knowledge. The Explore step allows students to deepen their understanding and challenges existing preconceptions and misconceptions, offering alternative explanations that help them form new schemata. In Explain, students communicate what they have learned, illustrating initial conceptual change. The Elaborate phase gives students the opportunity to apply their newfound knowledge to novel situations and supports the reinforcement of new schemata or its transfer. Finally, the Evaluate stage serves as a time for students' own formative assessment, as well as for educators' diagnosis of areas of confusion and differentiation of further instruction. This five-part sequence is the organizing tool for the Imagine Mars instructional series. The 5E stages can be cyclical and iterative.

2.0 Materials

Required Materials

Please supply:

• Equipment **Cards**	– 1 per team
• Design **Mat**	– 1 per team

- These can be downloaded from http://marsed.asu.edu/lesson_plans/marsbound

Please Print:

From Student Guide

(A)	Student Instruction Sheet	– 1 per student
(B)	Student Pre-Ideas Worksheet	– 1 per student
(C)	Activity 1 Fact Sheet: Mars Exploration Science Goals	– 1 per student
(D)	Activity 1 Science Objectives Worksheets	– 1 per team
(E)	Activity 2 Identify Your Mission Goals Worksheets	– 1 per team
(F)	Activity 3 Building Your Spacecraft Fact Sheet	– 1 per team
(G)	Activity 4 Spacecraft Design Log	– 1 per team
(H)	Activity 4 Engineering Constraints	– 1 per student
(I)	Activity 5: Identifying Constraints in Other Missions	– 1 per student
(J)	Student Post-Ideas Worksheet	– 1 per student
(K)	Comparing Rover Missions Fact Sheet (optional)	– 1 per team

Optional Materials

From Teacher Guide

(L) "Marsbound" Assessment Rubrics
(M) Placement of Instructional Objective and Learning Outcomes in Taxonomy

3.0 Vocabulary

Engineering Constraints	limits placed on your mission by the hardware you use to accomplish the mission.
Models	a simulation that helps explain natural and human-made systems and shows possible flaws
Predict	a declaration about what will happen based on reason and knowledge
Relative Distance	how far away objects are when compared to one another
Relative Size	how large objects are when compared to one another
Relationship	a connection between two objects
Scale	a comparative relation between objects such as size or distance

4.0 Instructional Objectives, Learning Outcomes, & Standards

Instructional objectives, standards, and learning outcomes are aligned with the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, which serves as a basis for upcoming "Next-generation Science Standards." Current National Science Education Standards (NSES) and other relevant standards are listed for now, but will be updated when the new standards are available.

The following chart provides details on alignment among the core and component NRC questions, instructional objectives, learning outcomes, and educational standards.

- Your **instructional objectives (IO)** for this lesson align with the NRC Framework and education standards.
- You will know that you have achieved these instructional objectives if students demonstrate the related **learning outcomes (LO)**.
- You will know the level to which your students have achieved the learning outcomes by using the suggested **rubrics** (see Teacher Guide at the end of this lesson).

Quick View of Standards Alignment:

The Teacher Guide at the end of this lesson provides full details of standards alignment, rubrics, and the way in which instructional objectives, learning outcomes, 5E activity procedures, and assessments were derived through, and align with, Anderson and Krathwohl's (2001) taxonomy of knowledge and cognitive process types. For convenience, a quick view follows:

WHAT IS THE UNIVERSE & WHAT IS EARTH'S PLACE IN IT?

NRC Core Question: ESS1: Earth's Place in the Universe

What are the predictable patterns caused by Earth's movement in the solar system?

NRC ESS1.B: Earth & the Solar System

Instructional Objective *Students will be able*	**Learning Outcomes** *Students will demonstrate the measurable abilities*	**Standards** *Students will address*	
IO1: **to design** a technological solution (mission) by making tradeoffs within constraints	**LO1a. to differentiate** between the purposes of scientific inquiry and technological design **LO1b. to analyze** requirements and constraints in a design task **LO1c. to construct** an appropriate science question (problem) requiring a technological design **LO1d. to generate** an appropriate technological solution within constraints **LO1e. to explain** the complex relationship between science and engineering design	**NSES (E): SCIENCE & Technology: Abilities of Technological Design** **Grades 5-8:** E1a **NSES (E): SCIENCE & Technology: Understandings about Science & Technology** **Grades 5-8:** E2a, E2c, E2d, E2e	**Rubrics in Teacher Guide**

This activity also meets the following standards:

21st Century Skills

- Creativity and Innovation
- Collaboration
- Social and Cross-Cultural Skills
- Productivity and Accountability

National Education Technology Standards (NETS-S)

- Creativity and Innovation
- Communication and Collaboration
- Critical Thinking, Problem Solving, and Decision Making

5.0 Procedure

PREPARATION (~10 minutes)

A. PRINT THE FOLLOWING:

• Equipment **Cards**	– 1 per team
• Design **Mat**	– 1 per team
• Student **Worksheets (A-K)**	– 1 per student

Teacher Tip: If you have printed the game board and cards from the website in black and white, ask your students to color the cards for you using a marker or colored pencil prior to laminating.

Color Key		
Game Board System	**Color**	**Coordinating Card #s**
Launch System	Red	1-6
Power System	Orange	7-12
Science Instruments	Blue	13-25
Mobility System	Fuchsia	26-27
Mechanical System	Yellow	28-30
Entry, Descent, & Landing System	White	31-35
Computer System	Purple	36-38
Communications System	Aqua	39-41
Special Events	Green	42-47

STEP 1: ENGAGE

Set up the Scenario of Mission Planning

A. Read the following:

Imagine that today, your school principal announces that you will be working on a new, very complex school project, a project that no one has ever done before. This project will be the single most important task you have ever been asked to complete thus far in your life. This project will be a group project, and you will be working with some people you know and others you don't know. Everyone in your entire group will need to complete the group project successfully or no one will pass. In fact, the project is so important, you will be working on it in every one of your classes, during an afterschool program, and as homework. You will probably be working on it at least 12+ hours a day and during many weeks; you will work through the weekend, too! You will have just 2 years to complete the project. The project is so complex and difficult, that you will have to revise and rewrite the plans for the project constantly. When the project deadline arrives, the group will have to show the completed project to the school, principal and, oh yes, all the news stations in the world will be there as well. You will have no extensions on the deadline. No pressure, but everyone is counting on you!

NASA mission planners, engineers, and scientists go through much the same process when designing and building space missions to Mars and other destinations. Many times, they are faced with tasks that have never been tried before. Imagine that they have spent 2 years of their lives, 12+ hours a day, planning, building, planning, testing, retesting, re-planning, re-building, re-testing, packaging, shipping, unpacking, testing, and re-testing, all in an attempt to do everything in their power to ensure their mission makes it to the surface of Mars.

B. Explain they will be playing a card game to design a mission to Mars. As part of "qualifying" for the mission planning, ask students to complete the Pre-Ideas.

This survey will help to establish their current understandings of mission planning and engineering constraints. Students will use this information during the Post-Ideas as part of their individual assessments.

C. Hand Out:

- **Marsbound! Student Guide (Worksheets A-K)** – 1 per student
- Equipment **Cards** – 1 per team
- Design **Mat** – 1 per team

Curiosity Connection Tip: For making a connection to NASA's Mars Rover "Curiosity," please show your students additional video and slideshow resources at:

http://mars.jpl.nasa.gov/participate/marsforeducators/soi/

STEP 2: EXPLORE

Construct a Science Question Requiring a Technological Design.

A. Activity 1: The purpose of this activity is to familiarize students with national goals for the exploration of Mars, and to enable students to categorize science questions according to these goals. Discuss NASA's four Mars Exploration Program goals and strategies with students. Working with their teams, students will categorize each question under each goal.

Teacher Tip: Keep in mind that a science question (mission objective) may apply to more than one science goal. There is no one "correct" answer; it is more important that your students can justify the reasons for the categorization.

NASA's four Mars Exploration Program goals

i. **Determine if life ever arose on Mars.** All life, as we know it, requires water to survive. In fact, on Earth we have found life wherever there is water, even in places we didn't think life could exist, such as frozen deserts of Antarctica. Is the same thing true of Mars? Because of the low temperatures and thin atmosphere of Mars today, we know that there is currently no liquid water on the surface of the planet. But was that always true?

ii. **Characterize the climate of Mars.** If we can understand what the climate of Mars is like today and how it changes, we will have a better idea of what the climate of Mars was like in the past. The atmosphere of Mars is mostly carbon dioxide, but two other important components are water vapor and dust. With enough information, we can begin to create a picture of the overall climate of Mars now and what it may have once been like.

iii. **Characterize the geology of Mars.** Rocks and minerals on the surface of Mars can tell us a great deal about a planet's past. By studying surface morphology and patterns and types of features found on the surface, we can find a permanent record of the history of Mars in its rocks.

iv. **Prepare for human exploration.** Humans are naturally curious. No robot will ever have the flexibility of a human explorer, so someday we will want to travel to Mars ourselves to study the planet and its history directly. Because of the difficulty and the number of challenges, robotic spacecraft must pave the way for humans to follow. One important task is to study new techniques for entering the Martian atmosphere and landing on the surface. We will also need to understand the dangers humans will face on the surface of Mars.

Differentiate between a Scientific Question and a Technological Design/Solution.

B. Activity 2: Student teams will discuss possible science objectives among themselves. Students will also determine a technological solution by deciding whether they want to fly a lander, orbiter, or fly-by mission to Mars.

Teacher Tip: Space is provided for 5 science goals, but your students will be hard-pressed to design a spacecraft (under budget) that can meet all five goals. This constraint is intentional, as it will guide them to revise their mission plan by going all the way back to the original Mission Goals page. This iterative process happens quite often in the real world as well.

Teacher Tip: In preparing students to make choices on whether to use a lander, orbiter, or fly-by, you can use the ***Strange New Planet*** activity (Lesson 6 in this collection) for a hands-on activity about exploring new planets.

Design a Technological Solution.

C. Activity 3: Student teams will begin to design the actual spacecraft that they will use for their mission. To facilitate this, each typical system that could be onboard a spacecraft is presented on its own "trading card." Students will need to read each card carefully, as the text provides clues about the uses and limitation for that particular piece of hardware.

i. Important! Hold the **(Green) Special Events cards** until the end of the simulation.

ii. Students will begin the simulation by choosing a **(Red) Rocket Card and Rocket Nose Cone** (required). The rocket card will determine the ***Mass Limit*** for the mission and will include the ***Cost*** in millions of dollars. The nose cone will be additional ***Weight*** and money, so students will need to record this information into their ***Spacecraft Design Log***.

iii. Students will then choose a **(Orange)** **<u>Power System Card</u>**. This card will determine the Power available during the mission.

iv. From here, students will choose their **(Purple)** **<u>Computer Systems</u>, (Aqua)** **<u>Communication Systems</u>**, and **(Blue)** **<u>Science Instruments</u>** cards to achieve their science goals stated in Activity 2. These will help to increase Science Return.

v. If students have chosen a rover or lander for their mission, rovers will need to include a **(Fuchsia)** **<u>Mobility System</u>**, and both rovers and landers will require **(White)** **<u>Entry, Descent, & Landing Systems</u>**.

vi. The final decision will be optional **(Yellow)** **<u>Mechanical Systems</u>**. These can increase the Science Return, but should be considered last due to budget constraints.

vii. Remind students to keep a tally in their Spacecraft Design Log to ensure they are staying within budget, power and mass.

Differentiation Tip: The teacher will need to define the budget. Lower amounts make it a more challenging activity, while higher amounts make it less challenging. Starting with $250 million is recommended as a good “average” level of difficulty for any of the missions.

viii. When students have created a mission within budget, power, and mass, they can now select a **(Green)** **<u>Special Events card</u>**. Half of these cards are Spin-offs or advances in technology that can be commercialized. These add money to the budget. The other half of the cards is failures or cuts to the budget. These take away money from the budget. Allow students time to adjust their mission to accommodate these scenarios.

Teacher Tip: Ask students to use a pencil on their Spacecraft Design Log so that they can easily erase when necessary.

ix. The final step will be launch day. ***Science Return*** will establish the order of launch. Start with the highest ***Science Return*** and falling under budget, mass and power. Students will roll the die to determine if their mission launched successfully. The type of rocket they chose will determine the success rate. For example, the Heavy-Lift Rocket is high risk, only lifting of successfully 3 out of 6 times. If students roll a 1, 2, or 3, they lift successfully. If they roll a 4, 5, or 6, launch fails and the mission is over.

STEP 3: EXPLAIN

Analyze Constraints within a Technological Design.

A. **Activity 4:** This activity focuses on the concept of engineering constraints. Encourage students to think of everything that limited what they attempted to do with their mission. Examples would include the limited mass that can be lifted by the rocket booster available, the electrical power that is required by each system onboard, and staying within the pre-determined budget.

Differentiation Tip: Ask students to consider other constraints that might limit a mission beyond what they discussed here. For example, a lander mission needs to be able to land safely in the terrain chosen to meet the science goals. After a little research, your students may realize that it is impossible to land safely in some kinds of terrain (such as mountains or the slopes of a volcano).

B. Ask students to share their constraints and accommodations with the class. The goal of this sharing process is to have the students listen critically to their peers' explanations, explain their own solutions, and question others' explanations.

After class sharing, take a few minutes to discuss and reaffirm some of the items they may have mentioned and highlight those missed (see bulleted list below.)

- **Size and Mass**: Some engineering constraints are due to the strength of the rocket you use to send your spacecraft to Mars. To send every instrument to Mars would require a rocket so large that it doesn't even exist.

- **Budget**: The United States Congress sets the budget, the total amount of money available to spend for each NASA mission. NASA must therefore, design missions to achieve as many science goals as possible, while still staying within budget. Bigger rocket boosters can carry bigger spacecraft. Unfortunately, they cost a lot more to launch.

- **Power**: Every spacecraft needs power in order to function. The more instruments that are onboard, the more power is needed for them to operate. ***Solar panels*** must be very large, but even so, still do not produce a lot of power. They require a great deal of direct sunlight to operate, so missions with solar panels are limited to being near the Martian equator, and can only operate for about 3 months of the year. ***Fuel cells*** create power through a chemical reaction much like batteries and produce a moderate amount of power, but they will only function for a limited period of time, generally only a few days or weeks. ***Radioisotope power systems*** (RPS) produce power from the heat generated by decaying radioactive materials. They produce a lot of power and can operate at any time of year and anywhere on the surface. They are quite heavy, extremely expensive, and require more precautions.

- **Reliability**: Some rockets are more reliable than others.

- **Bottom line**: Engineering constraints often force you to make trade-offs. These constraints may keep you from being able to achieve all of your science goals, so you have to choose the equipment that will allow you to achieve as many of your science goals as possible.

STEP 4: ELABORATE

Apply technological design skills to a novel problem.

A. Choose one of the following:

i. Ask students to identify at least 2 engineering constraints from the video and follow up with an explanation of how NASA may have overcome these constraints in the mission. This task should be in individual assignment to determine if students are able to apply their recently acquired knowledge to a new scenario.

ii. Rerun the simulation, but decrease the budget.

iii. Research possible landing sites to consider additional engineering constraints.

iv. Give student groups a copy of the Comparing Two Mars Rover Projects and ask them to reflect on the differences in the design of these Rover missions. What are some of the differences in engineering constraints that must have been overcome for each mission?

STEP 5: EVALUATE

Evaluate change in ability to solve engineering problems.

A. Post-Ideas: Ask students to complete the post-ideas. Students will need to refer back to the pre-survey and simulation to respond to these questions.

6.0 Extensions

Choose another activity from Step 4: Elaborate.

7.0 Evaluation/Assessment

Rubric*:* A rubric has been provided to assess student understanding of the simulation and to assess metacognition. A copy has been provided in the Student Guide for students to reference prior to the simulation. This rubric will allow them to understand the expectations set before them.

8.0 References

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(A) Student Instruction Sheet

Instructions:

For this activity, you will be placed in the role of scientist and engineer. Have you ever wanted to travel to Mars or maybe wondered what goes into the planning the mission to Mars? You and your team will design a potential mission to Mars. Just like the NASA mission designers, you will have a "catalog" of mission hardware from which you can choose. Also, just like the NASA mission designers, you will have budgets (mass, power and cost) that you must keep balanced.

Your mission will include the following 4 tasks:

1. Categorize current NASA mission goals for Mars;

2. Collaborate with your team in establishing your goals for the mission in alignment with NASA Mars Exploration Program Goals;

3. Design a mission that meets the requirements for balancing budget, mass, and power, achieves significant science return, and makes it safely to the planet; and,

4. Identify any engineering constraints that limited the capability of your mission.

Good luck planning your mission to Mars!

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(B) Student Worksheet. Pre-Ideas (1 of 2)

Please respond to the following questions as accurately and completely as you can.

1. What do you think would be the hardest part or parts of planning a mission to Mars? Explain why you think these items will be so difficult.

2. Define what you think a “good” mission to Mars would be and what the important elements of the mission during the planning are.

(B) Student Worksheet. Pre-Ideas (2 of 2)

3. Do scientists and engineers get everything they need and/or want when they are planning their missions? __________
4. Explain the reasons you think they do or do not get everything they request.

(C) Student Worksheet. Activity 1 Fact Sheet

NASA Strategies and Goals for the Exploration of Mars

Thousands of questions could be asked about Mars alone, so NASA has organized its program for Mars exploration around a common strategy. This strategy is the thread that ties together all four of NASA's main goals for Mars exploration. When designing a mission to Mars, mission planners define many science objectives related to each of the four science goals. These science objectives reflect questions about the planet that they would like the mission to answer.

Guiding Mars Exploration Program Strategies

Past:	"Follow the Water"	Found evidence of water, past and present
Current:	"Seeking Signs of Life"	Search for bio-signatures and return samples

Mars Exploration Program Goals

DETERMINE IF LIFE EVER AROSE ON MARS

CHARACTERIZE THE PAST AND PRESENT CLIMATE OF MARS

CHARACTERIZE THE GEOLOGY OF MARS

PREPARE FOR HUMAN EXPLORATION

Key Mars Discoveries: A Springboard to the Future

- Complex geological and climate history
- Diversity of ancient water-rich environments
- Environments that have potential to preserve bio-signatures
- Cold, dry planet today still changing
- Widespread subsurface ice provides resources for exploration and special environment for possible life today

(D) Student Worksheet. Activity 1: Sample Science Objectives (1 of 3)

Sample Science Objectives for Mars Missions

Here you will find a list of some of the science questions being studied by Mars scientists that can be selected as mission objectives—questions to be answered. For each science objective, place a checkmark in the box matching the Mars Exploration Program Goals that you think it matches. Keep in mind that each objective may apply to more than one of the four goals. Discuss with your team why you think each of these topics might be important. Write these reasons into the justification column of the table.

Science Objective	**Mars Exploration Program Goals**				**Justification**
	Determine if life ever arose	**Characterize the climate**	**Characterize the geology**	**Prepare for human exploration**	
Craters					
What kinds of craters are on Mars and how did they form?					
How old are the craters on Mars?					
How are Martian craters different from craters on the Moon?					
Have Martian craters been eroded by wind or water?					
Were some of the craters on Mars ever flooded?					
What kinds of rocks make up the ejecta from Martian craters?					
Has the amount of cratering on Mars changed over time?					

(D) Student Worksheet. Activity 1: Sample Science Objectives (2 of 3)

Science Objective	Mars Exploration Program Goals				Justification
	Determine if life ever arose	Characterize the climate	Characterize the geology	Prepare for human exploration	
Volcanoes					
What types of volcanoes are on Mars?					
Does Mars have moving continental plates?					
When/how often did the Martian volcanoes erupt?					
Have Martian volcanoes been eroded by wind or water?					
Did the lava from Martian volcanoes mix with water?					
Plains					
Were the northern plains on Mars once a huge ocean?					
Why is the northern hemisphere of Mars so smooth and flat, while the southern is so cratered?					
Polar Caps					
What are ice caps on Mars made of?					
How do the ice caps change throughout the Martian year?					
What are the dark lands/ features seen on Martian ice caps?					

(D) Student Worksheet. Activity 1: Sample Science Objectives (3 of 3)

Science Objective	Mars Exploration Program Goals				Justification
	Determine if life ever arose	Characterize the climate	Characterize the geology	Prepare for human exploration	
Canyons					
What formed the canyon systems on Mars?					
Did water ever flow through the canyons?					
Have the canyons been eroded by wind or water?					
Were some of the craters on Mars ever flooded?					
What kinds of rocks make up the ejecta from Martian craters?					
Has the amount of cratering on Mars changed over time?					

Take a few minutes, and with your team, write 3 of your own science questions (science objectives). Which Mars Exploration Program Goal does your question fall under and why?

Question (Science Objectives)	Mars Exploration Program Goals			
	LIFE	CLIMATE	GEOLOGY	HUMAN

(E) Student Worksheet. Activity 2: Identify Your Mission Goals

In (D) Activity 1, you classified a number of science objectives according to NASA's Mars Exploration Program goals. Your task for this activity is to select the science objective that you hope to achieve with your mission.

Using the list in (D) Activity 1 (including the objectives you created yourself), choose five science objectives for your mission. When your team has agreed upon the science objectives for your mission, record them in the table below. Record your team's reasons for why each objective is important. Be sure to explain how your objectives fit into NASA's Mars Exploration Program goals.

After discussing them with your team, rank your five science objectives from 1 to 5 in order of importance to your team **(1 being the most important)**. Ignore the final column for now.

Our mission will be (Circle one)

FLY-BY **ORBITER** **LANDER**

Rank Order (1-5)	Goal	Reason	Dropped

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(F) Student Worksheet. Activity 3: Building Your Spacecraft Fact Sheet

It is now time to build the spacecraft you will use to accomplish your mission objectives. Use the equipment cards and poster to complete this simulation. You will work with your team to design a spacecraft by assembling the cards that represent each system involved in your mission. Read each card carefully to make sure you have all of the required systems onboard your spacecraft.

Remember, your objective in this activity is to design a spacecraft with your team that stays under budget, is launchable, and meets your science goals. Your teacher will determine the budget of your mission and guide you through the initial steps of your mission design. You will need to record your design in the ***Spacecraft Design Log*** on the next page. You may go back at any time to change your science goals and your design. In the end, you should have a good balance between meeting your science goals and satisfying your engineering constraints.

Your teacher will give you your budget.

Example ***Spacecraft Design Log***:

System	Spacecraft Component	Budget 250	Mass 125	Power 50
Launch	Medium-Lift Rocket A	-100	0	0
		150	125	50
	Rocket Nose Cone	-10	-7	0
		140	118	50
Power	Fuel Cell	-40	-25	0
		100	93	50

Mass is determined by the rocket system and Power is determined by the power system that you choose.

The systems' names have been filled in.

Fill in the name of the item chosen. Erasures and changes may be necessary along the way.

The white boxes contain the cost, mass, and power for each card to be subtracted from your remaining budget. The blue box is the remaining budget after subtraction.

$ Cost in millions ⚖ Mass ⚡ Power ★ Science Return

(G) Student Worksheet. Activity 4: Spacecraft Design Log (1 of 2)

Spacecraft Design Log

System	Spacecraft Component	Budget	Mass	Power	Science Return
Launch					
Power					
Computer					
Communications					
Mobility					
Entry, Descent & Landing					
Science Instruments					
Mechanical					

(G) Student Worksheet. Activity 4: Spacecraft Design Log (2 of 2)

Mission Metrics

Special Events and Launch	Budget	Mass	Power	Science Return
Final Mission Costs (Record from the last row in the Spacecraft Design Log)				
Special Event Card Selected				
Final of Totals of Mission Design Categories				

1. **How did your final "Risk" card affect your mission?**

2. **Did your mission have a successful launch? (Circle one) Yes No**

3. **What are your thoughts about what you think of mission designs after this simulation?**

(H) Student Worksheet. Activity 4: Engineering Constraints

Engineering constraints are limits placed on your mission by the hardware you use to accomplish the mission.

With your team, recall the MARSBOUND! Simulation and brainstorm at least 3 hardware limitations you encountered along the way. For each of these encounters with constraints, describe how your team went about reworking your mission to accommodate these limitations.

Engineering Constraints and Accommodation List

	Hardware #1	Hardware #2	Hardware #3
Hardware			
Constraint			
Accommodation			

(I) Student Worksheet. Activity 4: Identifying Constraints in other Missions

To complete this activity, you will watch a NASA video on a current Mission to Mars.

Identify at least 2 engineering constraints from the current Mission to Mars.

1.____

2.____

For each constraint and using what you have learned in this activity, what accommodations do you think NASA has probably made for this mission to make it successful?

1.____

____

____

____

____

2.____

____

____

____

____

____

(J) Student Worksheet. Post-Ideas (1 of 2)

Based on the MARSBOUND! simulation, please respond to the following questions as accurately and completely as you can.

1. What do you think would be the hardest part or parts of planning a mission to Mars? Explain why you think these will be so difficult.

2. Refer back to your response to #1 in the Pre-Survey. Was your prediction accurate? ______ What reasons do you think caused allowed the prediction to be accurate or inaccurate?

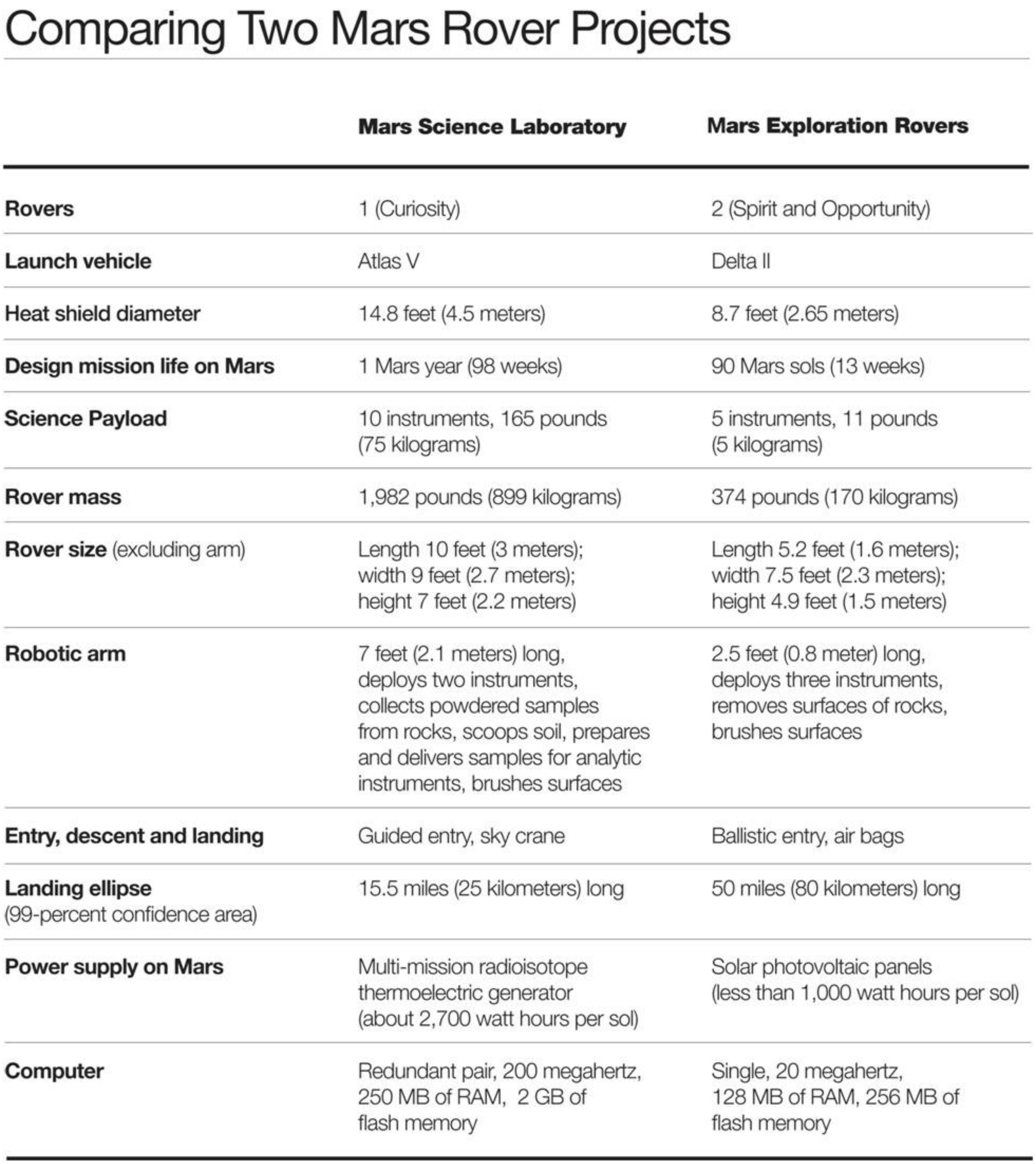
(J) Student Worksheet. Post-Ideas (2 of 2)

3. Define what you think a "good" mission to Mars would be? Why?

4. Do scientists and engineers get everything they need and/or want when they are planning their missions? __________.

5. Explain why you think they do or do not get everything they request.

(K) Student Fact Sheet. Comparing Two Mars Rover Projects



Comparing Two Mars Rover Projects

	Mars Science Laboratory	Mars Exploration Rovers
Rovers	1 (Curiosity)	2 (Spirit and Opportunity)
Launch vehicle	Atlas V	Delta II
Heat shield diameter	14.8 feet (4.5 meters)	8.7 feet (2.65 meters)
Design mission life on Mars	1 Mars year (98 weeks)	90 Mars sols (13 weeks)
Science Payload	10 instruments, 165 pounds (75 kilograms)	5 instruments, 11 pounds (5 kilograms)
Rover mass	1,982 pounds (899 kilograms)	374 pounds (170 kilograms)
Rover size (excluding arm)	Length 10 feet (3 meters); width 9 feet (2.7 meters); height 7 feet (2.2 meters)	Length 5.2 feet (1.6 meters); width 7.5 feet (2.3 meters); height 4.9 feet (1.5 meters)
Robotic arm	7 feet (2.1 meters) long, deploys two instruments, collects powdered samples from rocks, scoops soil, prepares and delivers samples for analytic instruments, brushes surfaces	2.5 feet (0.8 meter) long, deploys three instruments, removes surfaces of rocks, brushes surfaces
Entry, descent and landing	Guided entry, sky crane	Ballistic entry, air bags
Landing ellipse (99-percent confidence area)	15.5 miles (25 kilometers) long	50 miles (80 kilometers) long
Power supply on Mars	Multi-mission radioisotope thermoelectric generator (about 2,700 watt hours per sol)	Solar photovoltaic panels (less than 1,000 watt hours per sol)
Computer	Redundant pair, 200 megahertz, 250 MB of RAM, 2 GB of flash memory	Single, 20 megahertz, 128 MB of RAM, 256 MB of flash memory

(L) Teacher Resource. Marsbound! Rubric (1 of 3)

You will know the level to which your students have achieved the **Learning Outcomes**, and thus the **Instructional Objective(s)**, by using the suggested **Rubrics** below.

Instructional Objective 1: To design a technological solution (mission) by making tradeoffs within constraints

Related Standard(s) (will be replaced when new NRC Framework-based science standards are released):

National Science Education Standards (NSES)
(E) Science & Technology: Abilities of Technological Design
Identify appropriate problems for technological design. Design a solution or product; Evaluate completed technological designs or products; Communicate the process of technological design. (Grades 5-8: E1a)

National Science Education Standards (NSES)
(E) Science & Technology: Understandings about Science & Technology

Scientific inquiry and technological design have similarities and differences. Scientists propose explanations for questions about the natural world, and engineers propose solutions relating to human problems, needs, and aspirations. (Grades 5-8: E2a)

Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, and inquiry. (Grades 5-8: E2c)

Perfectly designed solutions do not exist. All technological solutions have tradeoffs, such as safety, cost, efficiency, and appearance. Engineers often build in back-up systems to provide safety. Risk is part of living in a highly technological world. Reducing risk often results in new technology. (Grades 5-8: E2d)

Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constraints limit choices in the design, for example, environmental protection, human safety, and aesthetics. (Grades 5-8: E2e)

(Associated rubric next page.)

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(L) Teacher Resource. Marbound! Rubric (2 of 3)

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1a: to differentiate between the purposes of scientific inquiry and technological design	Student can articulate the difference and provide many examples.	Students can articulate the differences and provide examples.	Student can somewhat articulate the differences.	Student is uncertain of the distinction.
LO1b: to analyze requirements and constraints in a design task	Design takes into account complexity of balancing budget, mass, power and science return. Modifies design significantly using pre-established science goals during the simulation.	Design accounts for complexity of balance between budget, mass, power and science return. Modifies the design during the simulation.	Design takes into account the balance between budget, mass, and power and therefore modifies the design during the simulation.	Design tends to focus only on Spacecraft components that are of interest to the builder, and is over budget, mass, and or power.
LO1c to construct an appropriate science question (problem) requiring a technological design	Mars Exploration Program Goals are chosen because the student is able to identify and explain the strong connection between water and the need to answer the science question to learn more about those water processes.	Mars Exploration Program Goals are chosen because the student is able to explain the water processes involved and/or how they work.	Mars Exploration Program Goals are chosen because student is able to identify that there is a connection to water processes, but may not be clear on what the processes are or how they work.	Mars Exploration Program Goals are chosen because the student likes or prefers them. Responses are often limited to 1 or 2 words.
LO1d to generate an appropriate technological solution within constraints	Justifications are based on experiences in the simulation and are relevant to engineering constraints. Demonstrates complexity of these constraints.	Justifications are based on experiences in the simulation and selects examples that partially describe the complexity in engineering constraints.	Justifications are based on experiences in the simulation. Student identifies examples from the simulation.	Justifications are based on misconceptions or previous understanding/beliefs. Uses personal preferences for justification.
LO1e to explain the complex relationship between science and engineering design	Post-survey responses demonstrate the student has connected to the complexity of mission planning and recognizes their new understanding of mission planning.	Post-survey demonstrates the student has connected to the complexity of mission planning using a variety of examples and explanations.	Post-Survey responses indicate an understanding of the connection between engineering constraints and a good mission.	Post-Survey responses tend to focus on one engineering constraints or are very similar to Pre-Survey responses.

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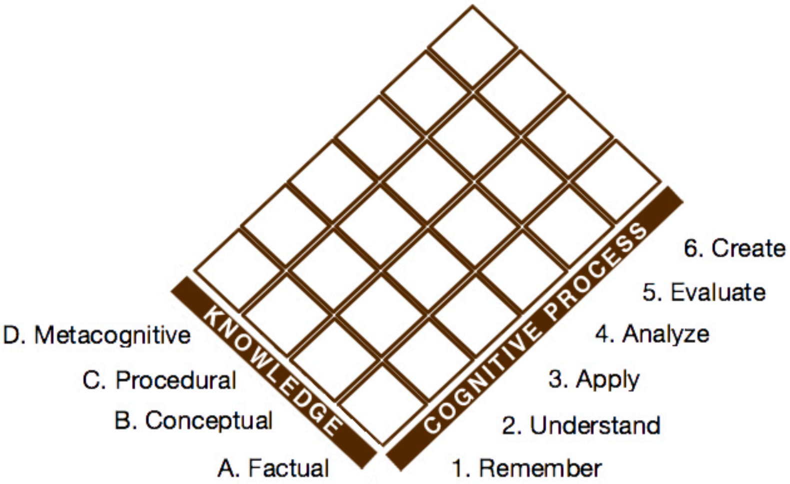
(L) Teacher Resource. Marsbound! Rubric (3 of 3)

21st Century Skills

Learning Outcome	Expert	Proficient	Intermediate	Beginner
Effectiveness of collaboration with team members and class.	Extremely Interested in collaborating in the simulation. Actively provides solutions to problems, listens to suggestions from others, attempts to refine them, monitors group progress, and attempts to ensure everyone has a contribution.	Extremely Interested in collaborating in the simulation. Actively provides suggestions and occasionally listens to suggestions from others. Refines suggestions from others.	Interested in collaborating in the simulation. Listens to suggestions from peers and attempts to use them. Occasionally provides suggestions in group discussion.	Interested in collaborating in the simulation.
Effectiveness in communication	Communicates ideas in a clearly organized and logical manner that is consistently maintained.	Communicates ideas in an organized manner that is consistently maintained.	Communications of ideas are organized, but not consistently maintained.	Communicates ideas as they come to mind.

(M) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (1 of 3)



This lesson adapts Anderson and Krathwohl's (2001) taxonomy, which has two domains: Knowledge and Cognitive Process, each with types and subtypes (listed below). Verbs for objectives and outcomes in this lesson align with the suggested knowledge and cognitive process area and are mapped on the next page(s). Activity procedures and assessments are designed to support the target knowledge/cognitive process.

Knowledge	**Cognitive Process**
A. Factual **Aa:** Knowledge of Terminology **Ab:** Knowledge of Specific Details & Elements **B. Conceptual** **Ba:** Knowledge of classifications and categories **Bb:** Knowledge of principles and generalizations **Bc:** Knowledge of theories, models, and structures **C. Procedural** **Ca:** Knowledge of subject-specific skills and algorithms **Cb:** Knowledge of subject-specific techniques and methods **Cc:** Knowledge of criteria for determining when to use appropriate procedures **D. Metacognitive** **Da:** Strategic Knowledge **Db:** Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge **Dc:** Self-knowledge	**1. Remember** **1.1** Recognizing (Identifying) **1.2** Recalling (Retrieving) **2. Understand** **2.1** Interpreting (Clarifying, Paraphrasing, Representing, Translating) **2.2** Exemplifying (Illustrating, Instantiating) **2.3** Classifying (Categorizing, Subsuming) **2.4** Summarizing (Abstracting, Generalizing) **2.5** Inferring (Concluding, Extrapolating, Interpolating, Predicting) **2.6** Comparing (Contrasting, Mapping, Matching **2.7** Explaining (Constructing models) **3. Apply** **3.1** Executing (Carrying out) **3.2** Implementing (Using) **4. Analyze** **4.1** Differentiating (Discriminating, distinguishing, focusing, selecting) **4.2** Organizing (Finding coherence, integrating, outlining, parsing, structuring) **4.3** Attributing (Deconstructing) **5. Evaluate** **5.1** Checking (Coordinating, Detecting, Monitoring, Testing) **5.2** Critiquing (Judging) **6. Create** **6.1** Generating (Hypothesizing) **6.2** Planning (Designing) **6.3** Producing (Constructing)

(M) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (2 of 3)

The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Pedagogically, it is important to ensure that objectives and outcomes are written to match the knowledge and cognitive process students are intended to acquire.

IO1: **to design** a technological solution (mission) by making tradeoffs within constraints (6.2; Bc)

LO1a. **to differentiate** between the purposes of scientific inquiry and technological design (4.1; Db)

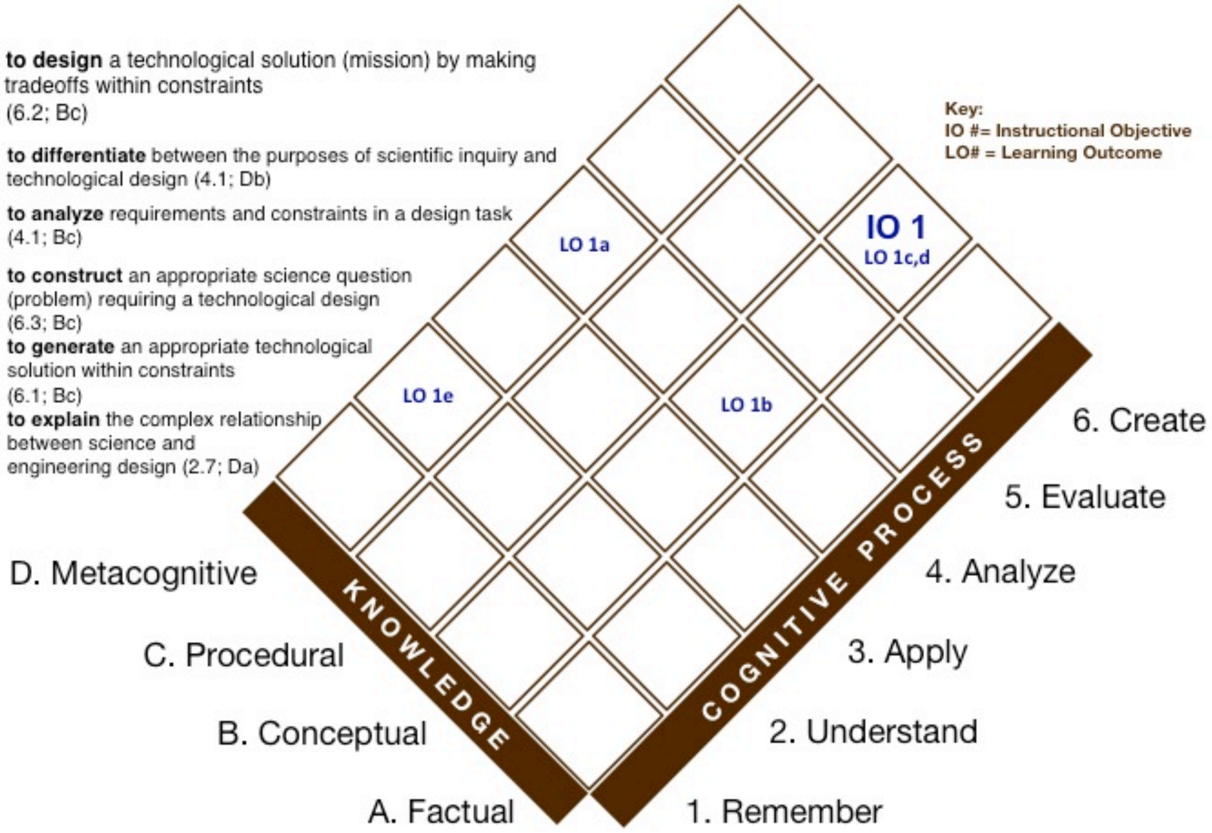
LO1b. **to analyze** requirements and constraints in a design task (4.1; Bc)

LO1c. **to construct** an appropriate science question (problem) requiring a technological design (6.3; Bc)

LO1d. **to generate** an appropriate technological solution within constraints (6.1; Bc)

LO1e. **to explain** the complex relationship between science and engineering design (2.7; Da)

Key:
IO #= Instructional Objective
LO# = Learning Outcome



(M) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (3 of 3)

The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Below are the knowledge and cognitive process types students are intended to acquire per the instructional objective(s) and learning outcomes written for this lesson. The specific, scaffolded 5E steps in this lesson (see 5.0 Procedures) and the formative assessments (worksheets in the Student Guide and rubrics in the Teacher Guide) are written to support those objective(s) and learning outcomes. Refer to (M, 1 of 3) for the full list of categories in the taxonomy from which the following were selected. The prior page (M, 2 of 3) provides a visual description of the placement of learning outcomes that enable the overall instructional objective(s) to be met.

At the end of the lesson, students will be able

IO1: to design solution w/model, inc. constraints
6.2: to design
Bc: knowledge of theories, models, and structures

To meet that instructional objective, students will demonstrate the abilities:

LO1a: to differentiate between inquiry and engineering design
4.1: to differentiate
Db: knowledge about cognitive tasks, inc. contextual and conditional

LO1b: to analyze requirements/constraints
4.1: to distinguish
Bc: knowledge of theories, models, and structures

LO1c: to construct an appropriate science question
6.3: to construct
Bc: knowledge of theories, models, and structures

LO1d: to generate solutions

6.1: to generate
Bc: knowledge of theories, models, and structures

LO1e: to explain sci/eng relationships

2.7: to explain
Da: strategic knowledge