Landing on the moon

Lunar Module Planning and Design

Short description

The students learn about cost calculation and resource management while working on this worksheet. Furthermore, they learn about the risks of a moon landing and have to assess these risks themselves in a risk analysis. Last but not least, the students learn about the differences between landings on the Moon and on Earth.

SHORT INFORMATION

School subject: Physics
Age group: approx. 12-15 years
Type of tasks: Arithmetic task, drawing task and experiment
Difficulty: Easy to medium
Time needed: approx. 2.5 h in total
Cost: medium (about 10 - 20 €)
Place: *Classroom*
You will need: Calculator, paper, straws, marshmallows, cotton balls, popsicle sticks, plastic bag, string, tape, scissors, balloons, 1 egg (per group), scale.
Keywords: physics, risk management

Learning objectives

Students learn,

- Know the basics of a moon landing
- Know the handling of resources in case of conceptualization
- Plan and conduct experiments
- Weigh risks
- Know the difference between landing on the moon or the earth
- Working as a team

Summary of activities

Activity	Title	Description	Result	Requirements	Time
1	Risk analysis and development of avoidance strategies	Fill in the risk matrix using the listed risks; develop 3 avoidance strategies.	Students learn to assess risks and evaluate them according to their impact.	None	Approx. 20 min
2	Concept study	Design and conceptualization of a lunar module; calculation of costs	Students learn how to calculate costs in the case of a planning phase; cost and weight of the Lunar Module.	Listed materials	Approx. 1 hr
3	Lunar Module Test	Lunar Module Test and Analysis of Results	The students test the lander and collect data. They calculate the acceleration and speed during landing.	Completion of task 1	Approx. 1 hr

4	Landing on the moon	Comparison of a landing on the moon with a landing on earth	Students learn the differences between the Moon and the Earth, calculate the acceleration due to gravity and the gravitational force.	Completion of task 2	Approx. 30 min

Introduction

Basics

The moon is a satellite of our earth. It is easily visible from Earth in the night sky and appears very large compared to the planets of our solar system. This is due to the proximity of the moon to our earth and because of this proximity, the moon is also very well suited as the first celestial body for the establishment of a station.

Just like the earth, the moon also revolves around itself. It also revolves around the earth. One revolution lasts one month.

On the moon itself it looks like a stone desert. There is debris and dust everywhere. In contrast to the earth, the moon has a lot of craters, which were formed by the impact of meteorites. The dark spots, which can also be made on the moon from the earth, are especially large craters, which are also called "seas".

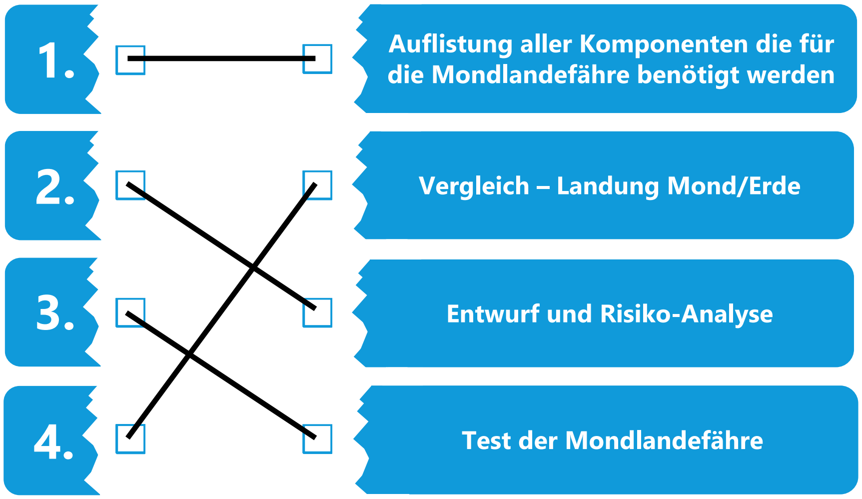
The atmosphere on our Earth, a shell of gas around our planet, protects us from meteorites because they burn in it. In addition, the Earth's atmosphere allows us to breathe. The moon does not have such an atmosphere, so meteorites can strike undisturbed and humans cannot breathe on the moon.

In addition, the temperature differences on the moon are enormous. If it is nighttime on the moon, it can get as cold as - 160 °C, whereas during the day temperatures can rise to 130 °C. Accordingly, there is no liquid water on the moon. Among other things, this is also due to the low pressure on the moon, which is the reason why water can only exist in solid or gaseous form.

The gravitational pull on the moon is also different from that on Earth. It is only about one sixth as large as that on our Earth.

Size of the Moon: *The earth is about 4 times the size of the moon*	3.475 km
Distance from Earth:	400.000 km
Temperature on the surface :	- 160 up to + 130 °C
Surface finish :	stony with many craters
Attraction:	$\frac{1}{6}$ the size of the Earth
Atmosphere : *No protection from meteorites, no breathing possible*	nonexistent

Preparation



1 - Lunar Module Design and Construction

In this assignment, students will use simple materials to design and build a lunar lander. The goal is to design a lunar module that can safely land an egg astronaut on the moon. In their planning, students must consider the risks of a manned lunar landing and conduct a risk study and a concept study.

Equipment

1x	*calculator*
1x	*Paper*
1xs	*traws*
1x	*Marshmallows*
1x	*Wadding balls*
1x	*Adhesive tape*
1x	*Cord*
1x	*Scissors*
1x	*Balloons*
1x	*Popsicle sticks*
1x	*Egg*
1x	*Scale*

Etc. at your own discretion

Solutions of the tasks

		Impact				
		Insignificant	**Low**	**Medium Heavy**	**Large**	**Catastrophic**
Probability	**Almost safe**		The lander is damaged during the test phase	The landing does not take place at the desired location		
	Probably		Another group has a cheaper/better design	Delays occur	Unexpected changes in requirements occur	The egg astronaut does not survive
	Possible		The lander is damaged during transport	The lander will be very heavy	Unexpected budget changes occur	The lander is damaged during landing
	Unlikely				Some materials are too expensive	Continuous change of the design leads to too high costs
	Rare				Some materials are no longer available	

Discussion

At the end of the assignments, it is a good idea to discuss some of the dangers of space exploration. Discuss with students the risks of losing an astronaut versus the cost of the lander. Should space exploration be done only with robots in the future? Before moving on to the second task (testing the lunar module), establish a definition for a "surviving egg astronaut." Is the egg allowed to have cracks? When is the mission considered successful?

2 - Lunar Module Test

In this task, students are to test whether their lunar module can survive a vertical drop and the egg astronaut survives. The landing should be documented. Optionally, groups can film their landing and then use a video analysis tool to study acceleration.

Equipment

1x	*Worksheet per group*
1x	*Self-built lander from task 1*
1x	*Camera/smartphone with tripod (optional)*
1x	*Video tracking program (optional)*
1x	*Computer/Smartphone (optional)*

For part 2, you need position and velocity as a time function. In this exercise, students will analyze velocity and acceleration during landing. As an example, we will use the data from Table 1 in Appendix 3. Students will need either a graphing calculator or a computer or smartphone with a program such as Microsoft Excel.

1. Calculate the impact velocity using the "Displacement in y-direction vs. time" graph:
   To calculate the impact velocity of the lander, students can first plot the ferry's displacement in the y-direction as a time function. Then they should perform a linear regression analysis of the data before impact (only for the last 10 to 5 data points before impact). The slope of this linear regression is approximately equal to the impact velocity. If the lander has not reached its terminal velocity, it is still accelerating. In this case, this method is only an approximation.
   In the example diagram (Fig. 1) the impact velocity is about 4.5 m/s.

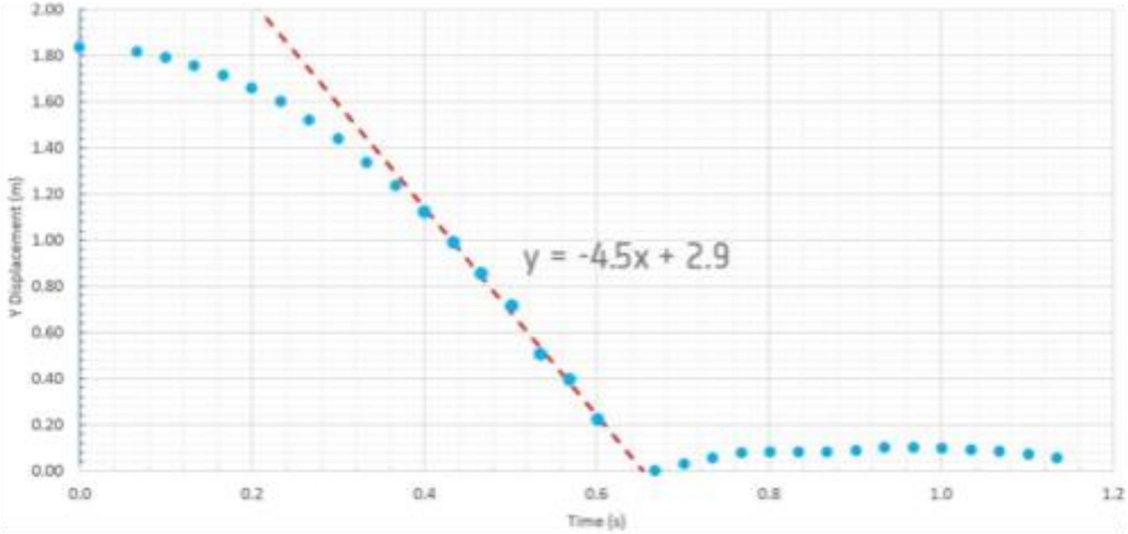


Figure 1

2. Determine impact velocity using velocity in y-direction vs. time: Another method of determining impact velocity is to plot the velocity in the y-direction as a time function. The approximate impact velocity can be easily identified in this graph as the point at which the velocity changes direction. In Figure 2, we see that the lander impacts the ground at a velocity of about 4.8 to 4.9 m/s, which is about the same as the velocity calculated in Task 1. The velocity of the lander should not decrease until impact (unless a recovery system such as a parachute is used, which is not the case here). The variations in the data points near impact are probably due to measurement inaccuracies.

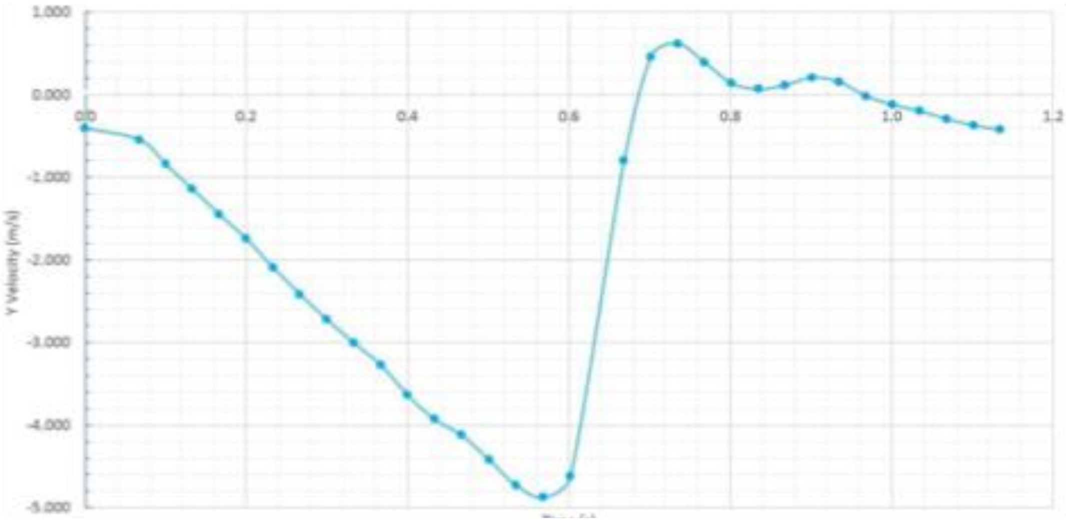


Figure 2

3. Calculating acceleration using the "velocity in y-direction vs. time" graph: To calculate the acceleration of the lander, students can perform a linear regression of the velocity in y-direction as a time function. The slope of this linear regression corresponds to the acceleration of the lander. Using the sample data from Figure 3, the acceleration in the y-direction can be calculated as y = -8.9x m/s2.

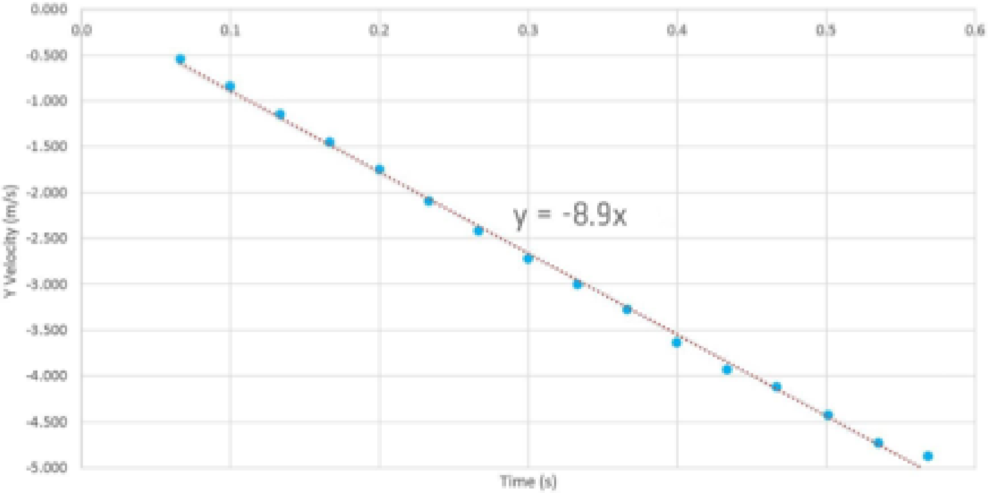


Figure 3

The influence of air resistance on acceleration: Due to the air resistance of the atmosphere, deceleration occurs. Air resistance increases with the square of the velocity. If the lander were dropped from a much higher point, students would be able to calculate the terminal velocity (constant velocity), which occurs when air resistance equals weight.

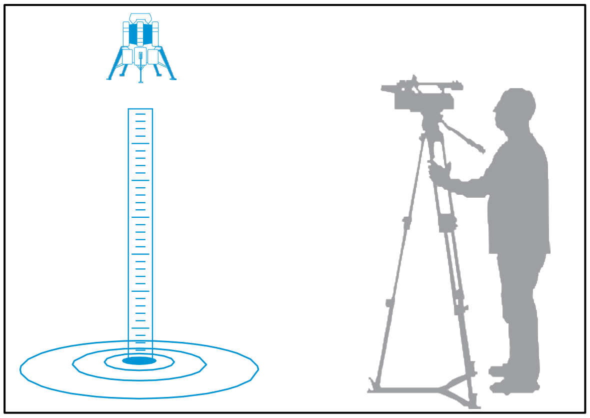
This part of Task 2 can either be demonstrated or continued as group work - depending on the availability of computers or smartphones.
With the help of a video analysis tool, the trajectory is tracked. There are several programs for this purpose - some are free, others require a license. We recommend the following programs:

- The "*Tracker Program*" can be downloaded free of charge from http://physlets.org/tracker/ and is suitable for use on a PC.
- The “Vernier Video Physics” app combined with “Vernier Graphical Analysis” (both available for Android and iOS) are ideal for use on a tablet or smartphone.

You can conduct an experiment and provide students with the data set or have each group conduct their own experiment.

Structure

1. Attach a meter stick as a reference next to the landing zone.
2. Position the camera so that both the landing zone and the meter stick are in the image.



3. It is best to use a tripod to keep the camera still.
4. When landing, make sure that the lander and meter stick are the same distance from the camera.
5. Track the landing in their selected program by manually setting markers.
6. Save the data.

Tracker program tutorials

youtube.com/watch?v=JhI- _glsE6o

youtube.com/watch?v=ibY1ASDOD8Y

3 - Landing on the moon

In this assignment, students will compare a landing on Earth with a landing on the Moon. They will investigate the different influencing factors and revise the design of their lander with the newly gained knowledge.

Solution of the tasks

To begin, discuss the differences between the Moon and Earth. What factors affect landing in both places? Guide students to discuss factors such as the importance of the landing site and the angle of approach.

a. Have your students each list 3 factors that can affect landing. Here are a few examples:

Landing on earth	Landing on the moon
1. Atmosphere	1. Position on the moon
2. Landing site	2. Landing site
3. Speed/angle during Re-entry	3. Landing speed
	4. Approach angle
4. Weather	5. Temperature fluctuations

Discuss the effects of the differences listed, for example, the atmosphere. How does the lack of an atmosphere affect landing on the moon? A parachute would not help with a lunar landing - they might need an engine or airbag instead. Heat shields are essential for re-entry into the Earth's atmosphere, but not for a lunar landing. Conversely, temperature fluctuations on the moon are much more extreme than on Earth, and the lander would have to be adapted accordingly.

b. To answer question 2, students need the equation for the acceleration due to gravity (g):

$$g = G \times \frac{m}{r^2}$$

G is the gravitational constant, m is the mass of the moon, and r is the radius of the moon. And Newton's second law of motion:

$$F = m * a$$

F corresponds to the force acting on a body, m is the mass of the body and a is the acceleration.

i)

$$g_{Earth} = G \cdot \frac{m_{Earth}}{r_{Earth}^2} = 9.81 \text{ m/s}^2$$

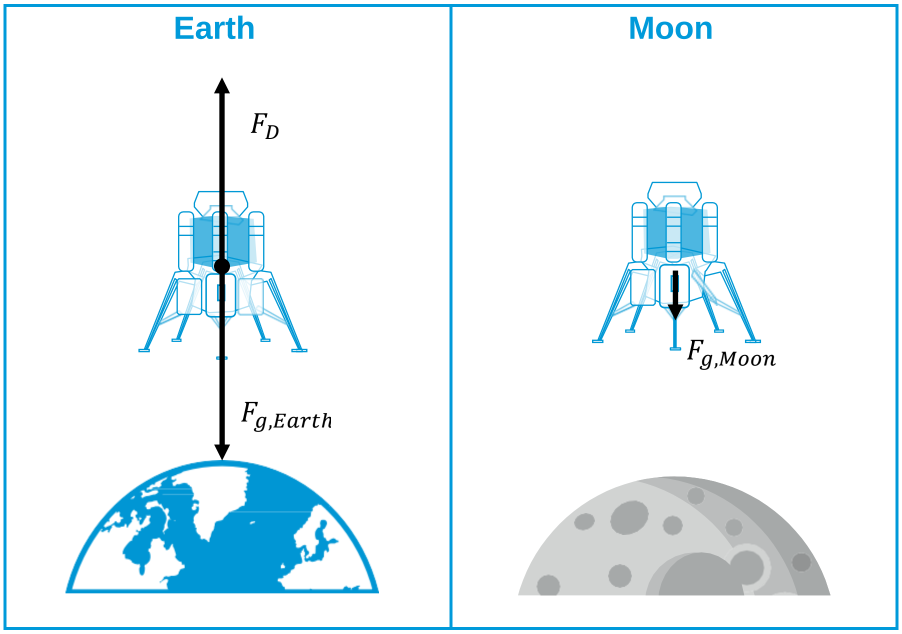
$$g_{Moon} = G \cdot \frac{m_{Moon}}{r_{Moon}^2} = 1.62 \text{ m/s}^2$$

ii)

$$F_{g,Earth} = m_{Lander} \cdot g_{Earth}$$

$$F_{g,Moon} = m_{Lander} \cdot g_{Moon}$$

c. *Have your students draw the force diagram of the lander on the Moon and on Earth.*



The moon is surrounded by airless space, accordingly the only force acting on the lander is the gravitational force ($F_{g,moon}$) or weight. The weight force vector is 6 times smaller on the moon than on the earth, as the calculation in task 2 shows.

The earth has an atmosphere, therefore the air resistance must be included. The air resistance (D) depends on the square of the speed of the lander. As the speed increases, the air resistance also increases until it equals the weight of the lander. As soon as this is the case, no more external force acts on the lander and it falls with constant speed (terminal velocity).

d. *Thanks to the knowledge gained from the previous tasks, the students should now know the differences between a lunar and an Earth lander. Discuss with the groups whether the use of a parachute is conceivable. Also discuss the advantages and disadvantages of airbags and thrusters. Ask the students if they would modify their lander if they did not have to ensure the safety of the astronaut. Use this opportunity to relate to real space missions and discuss the differences between manned and unmanned missions.*

WORKSHEET FOR STUDENTS

Landing on the moon

Lunar Module Planning and Design

Introduction

The moon is a satellite of our earth. It is easily visible from Earth in the night sky and appears very large compared to the planets of our solar system. This is due to the proximity of the moon to our earth and because of this proximity, the moon is also very well suited as the first celestial body for the establishment of a station.

Just like the earth, the moon also revolves around itself. It also revolves around the earth. One revolution lasts one month.

On the moon itself it looks like a stone desert. There is debris and dust everywhere. In contrast to the earth, the moon has a lot of craters, which were formed by the impact of meteorites. The dark spots, which can also be made on the moon from the earth, are especially large craters, which are also called "seas".

The atmosphere on our Earth, that is, a shell of gas around our planet, protects us from meteorites because they burn in it. In addition, the Earth's atmosphere allows us to breathe. The moon does not have such an atmosphere, so meteorites can strike undisturbed and humans cannot breathe on the moon.

In addition, the temperature differences on the moon are enormous. If it is nighttime on the moon, it can get as cold as - 160 °C, while during the day temperatures can rise to 130 °C. Accordingly, there is no liquid water on the moon. Among other things, this is also due to the low pressure on the moon, which is the reason why water can only exist in solid or gaseous form.

The gravitational pull on the moon is also different from that on Earth. It is only about one sixth as large as that on our Earth.

Size of the Moon: 3.475 km

The earth is about 4 times the size of the moon

Distance from Earth: 400.000 km

Temperature on the surface : - 160 up to + 130 °C

Surface finish : stony with many craters

Attraction: $\frac{1}{6}$ the size of the Earth

Atmosphere : nonexistent

No protection from meteorites, no breathing possible

In 1969, Apollo 11 became the first manned landing mission on the Moon. After a 4-day journey from Earth, the lander, the *Eagle*, detached from the command capsule orbiting the Moon and landed in Mare Tranquilitas, a relatively flat area. The lander was manually steered to avoid rocks and craters. "Houston, this is Tranquility Base. The Eagle has landed!" These words marked a new era of human exploration.

Apollo 12, the second manned lunar landing, was a precision exercise; much of the landing approach was automatic and the precise landing was of great importance because it was intended to increase confidence to land in certain regions.

The landing approach is one of the most critical and difficult phases in a lunar landing. The landing capsule must reduce its speed from 6,000 km/h in lunar orbit to a few km/h to ensure a smooth landing. Landing zones in interesting areas are often dangerous, full of craters, rocks and slopes, and consequently difficult to reach.

Before you start the actual development, you must first think about how to proceed with such a complex task. Please discuss this in your team and then connect the steps listed below in the correct order:

1.	☐	☐	**Auflistung aller Komponenten die für die Mondlandefähre benötigt werden**
2.	☐	☐	**Vergleich – Landung Mond/Erde**
3.	☐	☐	**Entwurf und Risiko-Analyse**
4.	☐	☐	**Test der Mondlandefähre**

Task 1: Design and build a lunar module

Now it's up to you to develop and build a lunar module with simple materials. The goal is to design a landing capsule with which your astronaut can land safely on the moon. In your planning you have to consider the risks for a manned moon landing and carry out a risk and concept study.

There is one more factor that you must not lose sight of - the cost. To promote efficient design, the purchase of materials should be 10% more expensive after the design phase is completed. You have a budget of 1 billion €. This budget should cover the cost of egg astronaut training (300 million €), launch (1 million € per gram), and materials. The individual costs are listed below:

- Mandatory costs:

Training of the egg astronaut:	300 million €
Launch costs:	1 million € per gram

- Material:

1 sheet A4 paper	50 million €
1 Straw	100 million €
1 Marshmallow	150 million €
1 Popsicle stick	100 million €
1 plastic bag	200 million €
1 m thread	100 million €
1 m adhesive tape	200 million €
1 balloon	200 million €

Design phase

Before you start building your lander, you should perform a risk analysis using the template provided. Enter the listed risks into the matrix.

Risk analysis

There are two critical factors to consider when planning a space mission: Risks and costs. For your mission, you need to make sure that the egg astronaut lands safely. At the same time, you must make sure that the mission is not too expensive.
Enter the listed risks into the risk matrix according to their probability of occurrence and potential impact:

		Impact				
		Insignificant	**Low**	**Medium Heavy**	**Large**	**Catastrophic**
Probability	**Almost safe**					
	Probably					
	Possible					
	Unlikely					
	Rare					

1. The landing does not take place at the planned location.
2. Unexpected changes in requirements occur.
3. The egg astronaut does not survive.
4. Unexpected budget changes occur.
5. Some materials are no longer available.
6. Some materials are too expensive.
7. The lander becomes very heavy.
8. Another group has a more efficient and/or cheaper design.
9. Continuous change of the design leads to high costs.
10. Delays occur.
11. The lander is damaged during the test phase.
12. The lander is damaged during transport.
13. The lander is damaged during landing.

Select three of the critical risks and develops avoidance strategies:

1) Risk #:______ Avoidance strategy:______________________________________

2) Risk #:______ Avoidance strategy:______________________________________

3) Risk #:______ Avoidance strategy:______________________________________

Now develop ideas for a safe lander that are within budget. To do this, make a concept study. Make a drawing of your idea and determine your budget using the costs listed above.

In addition, you need to make sure once again what the requirements are for you and in what framework they can be implemented in the end and it is possible for you to comply with them within the framework of your mission. Here is a brief reminder:

- The lander must pass a drop test and the egg-astronaut must survive the landing.
- You can use only the available materials.
- Only a certain budget is available for construction (maximum 1 billion €).
- The ferry should land exactly at the specified landing point.
- You will need to conduct a risk analysis and a concept study.

You must complete the ferry in the given time: 60 minutes

Concept study

Name of the landing ferry: _______________

Name of the egg astronaut: _______________

Look at the available materials and their cost. Make an accurate sketch of your lander. Describe how the various components and materials will protect your Egg-astronaut. Based on the cost of the materials, determine a budget for your lander and don't forget to include the cost of Egg-astronaut training and launch:

Material	Piece price	Quantity	Cost

Costs for the landing ferry	
Total weight (Egg astronaut + ferry)	
Start costs	
Egg astronaut training costs	
Total cost	

Task 2: Lunar Module Test

Now the time has come - the test of your Lunar Module is coming up! Now you have to test if the lunar module can survive a vertical fall and if the astronaut survives. Document all relevant data. If you want to make it a bit more technical, then use a help software for your smartphone.

a) Make a note of the landing conditions (wind, rain, hardness of the ground, etc.) before takeoff.

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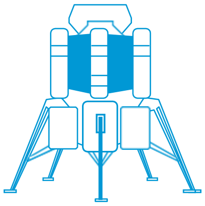
Before the launch, make sure your egg astronaut is comfortable. Prepare for the test.

Attention! Ready! Go!



b) Did your egg astronaut survive? **Yes** ____ **No** ____

c) How far from the target area did the ferry land? _______________ **cm**

d) How well did your plan work? Would you change anything? If so, what?

____

____

____

Task 3: Landing on the moon

It's time to prepare for landing on the moon. You've tested your lander on Earth, but what happens when it lands on the Moon? For this, the landing on the moon and on the earth are to be compared in the following. Examine the various influencing factors and use the new findings to revise the design of your lander.

a) There are many differences between the Moon and Earth. List 3 factors that influence a landing on the Moon or on Earth:

Landing on earth	Landing on the moon
1.__________________________ 2.__________________________ 3.__________________________	1. _________________________ 2.__________________________ 3.__________________________

b) The gravitational acceleration (g) of a planet is described as follows:

$$g = G \times \frac{m}{r^2}$$

G is the gravitational constant, m is the mass of the planet (or moon), r is the radius of the planet (or moon). Use the values given below to answer the questions a. and b.:

$G = 6.67408 \times {}^{10\text{-}11 \text{ m3 kg-1 s-2}}$

$r_{Moon} = 1737$ km

$m_{Moon} = 7.35 \times {}^{1022}$ kg

$r_{Earth} = 6371$ km

$m_{Earth} {}_{=} 5.97 \times {}^{1024}$ kg

i. Calculates the gravitational acceleration on Earth and on the Moon

$g_{Earth} =$

$g_{Moon} =$

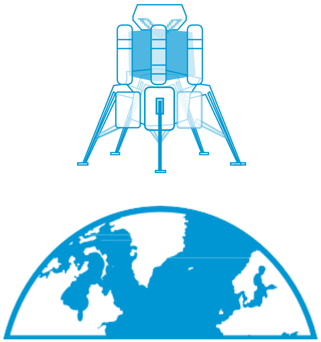
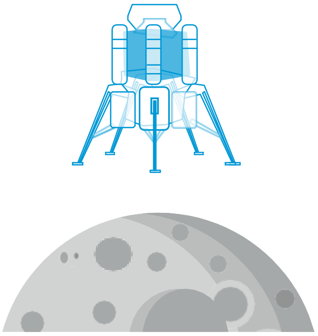
ii. Using Newton's second law F = m*a, calculate the gravitational force of your lander on the Moon and on Earth.

$F_{g,Earth}$ =

$F_{g,Moon}$ =

c) Forces on Earth and Moon

Draw in the forces acting on the lander on the Moon or on Earth.

Earth	**Moon**
	

Explain your force diagram.

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What would you change to better prepare your lander for a moon landing?

Explain your ideas.

Links

ESA Resources

ESERO Germany website: www.esero.de

ESERO Germany Worksheets: www.esero.de/materialien/arbeitsblaetter

ESA classroom resources: www.esa.int/Education/Classroom_resources

ESA Kids Homepage: www.esa.int/kids