Teaching material 3 (Teachers)

Overview

Topics:	Earth-Moon relationship, astronomy, remote sensing – must be carried out after teaching material 1
Subjects:	Geography, Physics (astronomy)
Grade:	9-13
Media & Material:	Maps from Lunaserv remote sensing data, augmented reality app “Columbus Eye”, worksheet
Duration:	90 – 135 minutes
Key question:	How do tidal forces affect the Earth **and** the Moon? In the past, today, and in the future? Why is the Moon so important for (human) life on Earth?

Competences

Subject competences

The students...

... describe and explain the tidal forces between the Earth and the Moon and show how the current Earth-Moon relationship has an effect on the two celestial bodies.

... describe and explain how tidal forces and the Earth-Moon relationship have changed over the last 4.5 billion years since the Moon was formed, and present theories about the "dark side of the Moon" (*supported by Lunaserv*).

... analyze how the tidal forces of the two celestial bodies will change in the future.

... analyze what effects the disappearance of the Moon would have on the Earth and on humans.

Methodological competences

The students...

... use satellite-based and ground-based data of the Moon to analyze the facts.

... use a combination of worksheets and Lunaserv material to find ways of presenting more complex presentation materials and working materials, graphically and linguistically.

... experience the process of gaining knowledge by discussing their approaches and results.

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum

Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

Judgmental competences

The students...
... evaluate their methodological approach regarding the tidal forces and their effects in relation to both celestial bodies in the past, present, and future.
... assess how suitable the materials provided are for the work assignments and to what extent there is potential for improvement in the materials.

Executive competences

The students...
... present work results in a relevant manner and using appropriate technical language.

Curriculum

This lesson focuses on the process of gaining knowledge, a process-related skill. It is not possible to establish direct links to the lunar analyses in all of the core curricula of the federal states. However, there are at least some possibilities for linking to existing content areas. In physics, this relates to the astronomical component and the theory of gravity, and in geography to the Earth-Moon relationship and remote sensing.

This unit covers many sub-skills of knowledge acquisition that are evident in scientific ways of thinking and working. Specific examples of curriculum relevance can be found in the table below. Note, that all presented topics are implemented into the curriculum of the german federal states only.

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum

Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

Subject	Geography	Physics
Topics	Earth-Moon relationship, remote sensing	Astronomy, Earth-Moon relationship
Baden-Württemberg	9/10: Digital orientation (GIS, remote sensing), endogenous and exogenous processes 11/12: The Earth-Moon system, spheres in the Earth-Moon system	9/10: Mechanics and dynamics 11/12: Gravitational fields, advanced topics in astrophysics, cosmology
Bavaria	10: Geographical working techniques and methods 11/12: Geographical working techniques and methods, geological processes (in the alternative geology curriculum)	10: Astronomical world views, profile area at NTG (forces in accelerated reference systems), cosmology
Bremen	Qualification phase: Physical geography fundamentals and processes	Qualification phase
Berlin	Introductory and qualification phase: Geosphere, endogenous processes	Introductory phase: Earth's rotation (Moon), movement of artificial satellites, gravity Qualification phase: Gravity, tides, space travel
Lower Saxony	Upper secondary level: physical and geographical factors, spatial orientation	(upper secondary level)
North Rhine Westphalia	Introductory and qualification phase: changing significance of location factors	Introductory phase: circular motion, gravity, and physical worldviews
Thuringia	-	11: Gravitation (weight, tides, planetary motion), circular motion 12: Gravity

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum
Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

Didactic commentary

The teacher introduces the topic by writing the key question on the board: **"How do tidal forces affect the Earth and the Moon? In the past, today, and in the future. Why is the Moon so important for (human) life on Earth?"** The teacher then moves on to defining centrifugal force and centripetal force. The students should first provide their own input on the two definitions before receiving the worksheet. Next, the students receive the worksheet, read the two short definitions, and then the letter, which serves as a starting point for the topic. In it, Johanna writes to her friend Marie about her vacation at the North Sea and asks her how exactly the phenomenon of tides occurs on Earth. The letter is to be answered by the students at the end of the lesson.

The students then begin to work on the tasks. The first task relates to the relevance of the tides, and the students are asked to activate their prior knowledge with the help of a mind map. The students then look at homogeneous and inhomogeneous gravitational fields and artificial gravity. As this is a rather complex topic, the knowledge is consolidated in a plenary session after task 2.1 to prevent any misunderstandings that could hinder the lesson.

After this, the students work independently on the calculation in task 2.2, and the results are then briefly discussed in a plenary session. The sub-tasks of task 3 address the topic of tidal locking using the example of space ropes. The aim is to strengthen students' understanding of gravitational forces in the Earth-Moon system through individual and partner work. After task 3.2, the class reviews the material to ensure that students are able to complete task 3.3 as easily as possible. The results of the gravitational acceleration calculation are then also discussed in class.

The augmented reality app "Columbus Eye" will be used more frequently as an interactive teaching tool in the following tasks. The students work on 3.4 regarding relief and global crustal thickness and 3.5. regarding tides on Earth using the information provided on the worksheet and in the app. The results are then compiled in a plenary session. The app conveys the content to the students in an interactive way.

This is followed by further app-based tasks on the tides of the Earth, the Moon, and the Earth-Moon system. Finally, the students should work in pairs to explain the formation of the tides. This should be followed by a letter to Johanna explaining the tides. As a final interim review, the results of tasks 3.6 to 3.9 are to be compiled in a plenary session and individual letter responses from task 4 are to be presented.

If necessary, two additional tasks are also available. These deal with the geographical effects on the strength of the tides on the one hand and the potential consequences for the Earth if the Moon were to disappear on the other.

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum

Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

Lesson plan

Time	Phase	Lesson activities	Methodological-didactic Comments	Social form	Media
15 min	Introduction	Key question and introduction with a letter about the tides.	Introduction in plenary session followed by individual work.	Class discussion, Individual	Board + worksheet
10 min	Development 1	The students develop a mind map on the relevance of tides in the Earth-Moon system.	The prior knowledge of the individual students will be activated. The students brainstorm their ideas on a new topic and note down their considerations.	Individual	Worksheet, interactive tool
5 min	Interim review	The students present their results and ideas to the whole class.	The teacher notes the results in bullet points on the board. This interim assessment gives the teacher an overview of the students' prior knowledge and allows them to better track learning progress at the end of the lesson.	Class discussion	Board / Projector
10 min	Development 2	The students work on homogeneous and inhomogeneous gravitational fields and complete the task.		Individual	Worksheet
5 min	Interim review	The students compile the results in a plenary session.	The interim assessment in the plenary session is extremely important after the theoretical introduction.	Class discussion	Board / Projector

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum

Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

5 min	Development 3	The students calculate the center of gravity of the Earth and the Moon.		Individual	Worksheet
5 min	Interim review	Brief compilation of the results from the calculation.	Clarification of errors in the calculation.	Class discussion	Board / Projector
15 min	Development 4	Introduction to tidal locking using space ropes. The students then work on the tasks.		Individual + partner work	Worksheet
10 min	Interim review	The results are discussed in a plenary session.		Class discussion	Board / Projector
5 min	Development 5	The students calculate the gravitational acceleration in the capsule and compare it with the acceleration due to gravity.		Individual	Worksheet
5 min	Interim review	Brief compilation of the results from the calculation.	Clarification of errors in the calculation.	Class discussion	Board / Projector
10 min	Development 6	The students work on the next two tasks (3.4. and 3.5.).	Use of worksheets in combination with the interactive AR app.	Individual	Worksheet, interactive tool
10 min	Interim review	The students discuss the results in a group discussion.		Class discussion	Board / Projector
15 min	Development 7	Tasks 3.6. to 4. are completed individually and partly in pairs.	Use of worksheets in combination with the interactive AR app. The introductory question is concluded with a final	Individual + partner work	Worksheet, interactive tool

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum
Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

			explanation of the tides and the letter response.		
10 min	Review	As a final review, the results of tasks 3.6. to 3.9. should be compiled in a plenary session and some of the letters from task 4 should be presented in class.		Class discussion	Board / Projector

Possible solutions to the students' tasks

1. Why are tides important and why should they be observed?

- Renewable energies; tidal power plants (energy generation), e.g., in St. Malo at the mouth of the Rance River, where one of the largest tidal ranges in the world is reached
- Birds that can only feed on the mudflats at low tide
- Fish swarm during a full Moon
- Animal species that spawn in accordance with the tidal cycle
- Risk of flooding
- Influence of the Earth-Moon system on the two celestial bodies

2. Homogeneous vs. inhomogeneous gravitational field

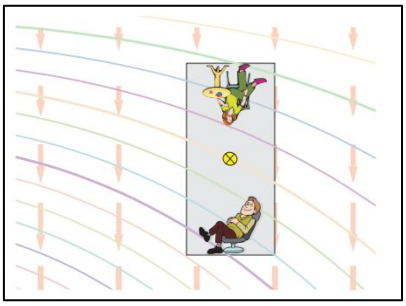
The two figures show the parabolic trajectories of two boxes in two different gravitational fields. Each box contains a hammer and a volleyball. The center of gravity is marked with an X. In both figures, weightlessness acts on the center of gravity of the box in free fall. The left figure shows the homogeneous gravitational field. Here, all objects remain in the same position in the box and weightlessness acts due to free fall. The figure on the right shows the trajectory of the box in the inhomogeneous gravitational field. Here, the center of gravity of the box also remains in weightlessness. However, the hammer and volleyball experience tidal acceleration toward the upper edge (hammer) and toward the lower edge of the box (volleyball).

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum

Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

2.1. Artificial gravity

Weightlessness continues to prevail in the middle of the box. Above and below the center of gravity, artificial gravity prevails in different directions. In the lower part of the box, you can stand on the floor; in the "upper" part, however, you are pressed against the "ceiling." "ceiling." You will place your feet there and define the "ceiling" as "down":



2.2. Center of gravity between Earth and Moon

Result approx. 4700 km, so the center of gravity lies within the Earth, approx. 1700 km below the Earth's surface. The center of gravity of the Earth is accelerated more strongly than the mass elements located on the side of the Earth facing away from the Moon. This leads to an elastic deformation of the solid Earth and to the second flood mountain on the side facing away from the Moon. The Moon and the Earth attract each other. There is a gravitational force between them.

3. Space ropes and tidal locking

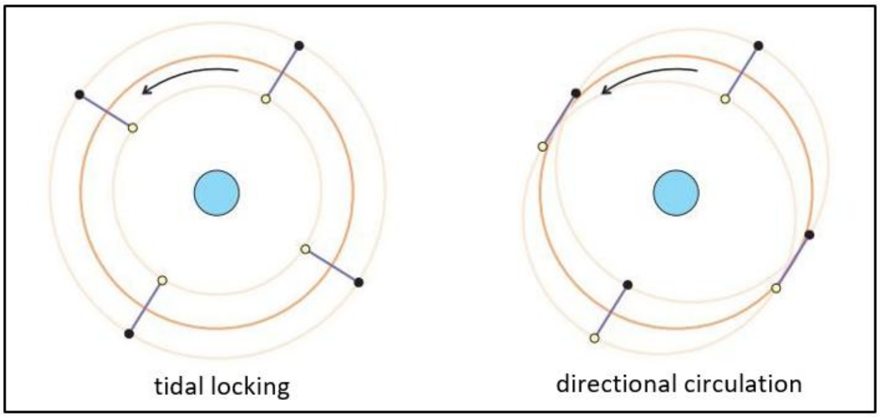
3.1. Experiment: Object in capsule

As long as you hold the ball, your arm exerts the "rope force" that keeps the ball stationary relative to the capsule. If you release the ball, it accelerates outward until it is stopped by the rope-covered wall of the capsule. The ball remains there because the wall now exerts the strongest force on it.

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum
Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

3.2. Centripetal force and the orbit of the Moon

- The space rope mentioned above runs in a bound rotation around the Earth, just like the Moon.
- The outer capsule (black) orbits the Earth at a greater distance than the center of gravity
    - ➢ Therefore, a greater centripetal force must act on it, which contributes to the rope tension. Bound rotation is a stable form of motion for the space rope.



3.3. Task: Gravitational acceleration

The gravitational acceleration is obtained from the equation for rope force by dividing by m. When inserting the values, it must be ensured that r_S is not the distance of the rope from the Earth's surface, but from the center of the Earth. Therefore, $r_S = r_E + 400\ km = 6370 km + 400 km = 6770\ km$. In addition, $\triangle r$ is half the rope length, in this case 25 km. Further information is provided by the Earth's mass $m_E = 5.97 * 10^{24} kg$. This gives us:

$$\alpha_{tide} = \frac{F_{rope}}{m} = 3 * 6,67 * 10^{-11} \frac{m^3}{kg * s^2} * 5,97 * 10^{24} kg * \frac{25 * 10^3 m}{(6770 * 10^3 m)^3}$$

$$\alpha_{tide} = \frac{F_{rope}}{m} = 0{,}096 m/s^2$$

The artificial gravity in the capsules corresponds to approximately one percent of Earth's gravity (0.01g).

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum

Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

3.4. Differences between near and far side of the Moon

Due to the tidal locking, it is assumed that centrifugal force caused the Moon to develop a much thicker crust and higher relief on the side facing away from Earth after cooling, as the lava accumulated there.

However, this is only one possible reason. Earlier volcanic activity and long-term geological processes, as well as meteorite impacts on the Moon, may also have caused this phenomenon. The reason is most likely a combination of all these explanations.

3.5. High and low tides

Since the Earth also rotates on its own axis, it rotates beneath the two tidal bulges and the ebb zones. The tides of the Moon have an average period of 12 hours and 25 minutes. While the Earth rotates on its axis, the Moon also moves a little further in the same direction in its monthly orbit. As a result, the tides caused by the Moon shift backwards by approximately 53 minutes each day. For the tidal effect of the sun, the corresponding shift is only about 4 minutes.

3.6. Tidal forces on the Moon

Tidal locking of the Moon.

The tidal forces act differently on Earth due to the different position of the Moon compared to the Moon, where the position only changes slightly because the Earth is always at a similar point on its synchronized orbit as seen from the Moon. However, there are slight changes in rotation, which also cause the slight wobbling motion of the Moon (libration) and strong moonquakes.

The magnitude of tidal forces depends on the distance between the bodies or objects affected.

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)

AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum
Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

3.7. Calculation of the Roche limit

For rigid bodies: $d = 6{,}371 * \sqrt[3]{\frac{2*5{,}514}{3{,}344}} = 9.483$

Für liquid bodies: $d = 2.423 * 6{,}371 * \sqrt[3]{\frac{5{,}514}{3{,}344}} = 18.237$

- Die true Roche limit usually lies between these values but is difficult to determine because other factors such as deformability and the exact density distribution must be taken into account.

3.8. Formation of tides based on the Moon and the Sun

The tides on Earth are probably the best-known consequence of the gravitational system between Earth, Moon, and Sun. Despite its smaller size and much lower mass, the Moon has an effect on the Earth's tides. The Sun also has a gravitational effect on the Earth, but this is three times weaker than that of the Moon due to its greater distance from Earth.

A fixed point on the Earth's surface constantly changes its position due to the Earth's rotation. This results in a 12-hour cycle of high and low tides. We only perceive the time-dependent part in the 6-hour cycle of high and low tide. There is a slow but steady deceleration of the Earth's rotation and thus an increase in the length of the day (just under 2 ms per century), i.e. the Earth loses angular momentum due to friction and heating when the Earth's crust rotates beneath the tidal bulges.

3.9. Spring tides and neap tides

The influence of the sun in combination with the Moon causes particularly strong tides (spring tides) and particularly weak tides (neap tides) on Earth. The strength of the tides varies depending on the position of Earth, Moon, and Sun. For example, the celestial bodies are either positioned in a way that the gravitational forces add up (spring tides) when the Sun, Moon, and Earth are aligned, as it is the case during a full moon and new moon, or the forces act in opposite directions (neap tides). The tidal forces are weakest during the first and last quarter moons, when the Sun and Moon are at the right angles to each other.

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)
AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum

Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.

Addendum 5. Geographical influence of tides on Earth

The geographical location of a place on Earth influences the strength of the tides. The shape of the coastline and the geological composition of the seabed can amplify or weaken the tides. In some areas, such as narrow bays or river mouths, the water can be more strongly dammed up, leading to higher tides. In other areas, such as large open oceans, the tides may be less pronounced. Ocean currents and underwater structures such as reefs and islands can also influence the movement of water and make tidal patterns more complex.

Addendum 6. Life without the Moon

Without the Moon, the Earth would rotate much faster. A day on Earth would then last approximately 9-10 hours. Wind speeds would increase. Only very flat and adapted creatures would survive the changed situation. In addition, the Earth's axis of rotation would be much more unstable and would fluctuate greatly. Potentially, the North Pole could then be at the zenith of the sun, which would cause drastic changes on Earth in terms of climate, flora, and fauna, and would make life on Earth practically impossible. Furthermore, only the sun would influence the tides. This would mean that the tides would be weaker, but the fast rotation of the Earth would cause storm surges and tsunamis. In addition, there would be little to no light at night, which would also have a decisive impact on fauna and lead to the extinction of many species. Some animals spawn in accordance with the lunar and tidal rhythms.

Author: Roman Hiby (roman.hiby@rub.de); Contact: Jun. Prof. Dr. Andreas Rienow (andreas.rienow@rub.de)

AG Geomatics – Interdisciplinary Geoinformation Sciences, Institute of Geography, Ruhr-Universität Bochum
Funding: By the German Space Agency at the German Aerospace Center with funds from the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag under the funding code 50TD2201.