Teaching Material 1 (Students):

What is the geological composition of the Earth and the Moon, and what does this tell us about the formation of the Moon?

The map content is also integrated into the Augmented Reality application “Columbus Eye” so that it can be viewed and to interact with it.

Formation theories

The Moon is a particularly unique celestial body. No other planet in the solar system has a moon as large in proportion to its size as Earth does. But how did the Moon actually form? In recent decades, scientists have developed various hypotheses about the formation of the Moon. But which of these is most likely to be true? Step into the role of a scientist and find out!

1. The following four formation theories will be compared in terms of probability at the end. First, read through the short information texts.

   1.1. Collision theory

   The collision theory states that approximately 4.5 billion years ago, Earth was struck by a protoplanet with about two to three times the mass of Mars and smaller than Earth. The protoplanet was completely destroyed, and its fragments merged with Earth to form the Moon over a period of years.

   1.2. Capture theory

   The capture theory states that the Moon was a traveling celestial body, such as an asteroid, and was pulled into a stable orbit by the gravitational force of the Earth. This can be explained by the Moon's much lower mass compared to the Earth and an optimal angle of incidence and speed.

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1.3. Co-formation theory

The Co-formation theory states that the Moon formed in the solar system at the same time as Earth, around 4.5 billion years ago, and was created by Earth-like processes such as collision and accretion (increase/accumulation).

1.4. Fission theory

The fission theory states that the Moon was formed at the same time as the Earth, but not through accretion (increase/accumulation), but rather through a rotating Earth that hurled a large chunk of material into space, which then developed into the shape and orbit of the Moon.

2. First, work on the following tasks individually:

2.1. Look at the side of the Moon facing Earth and the side facing away from Earth and compare the differences. You can also find the maps in 3D in the app.

The Moon and the Earth are bound together by gravitational forces. Their rotations are synchronized so that we can only ever see one side of the Moon from Earth. Humans did not see the side of the Moon facing away from Earth until 1959, when a Soviet spacecraft flew past it. The surface of the Moon is solid, rocky, and shaped by external (exogenous) processes in the form of meteorite or asteroid impacts.

With the help of remote sensing, the near side and far side of the Moon can be analyzed globally for a wide variety of properties. This can be viewed on maps. The Columbus Eye augmented reality app provides another way to visualize remote sensing data.

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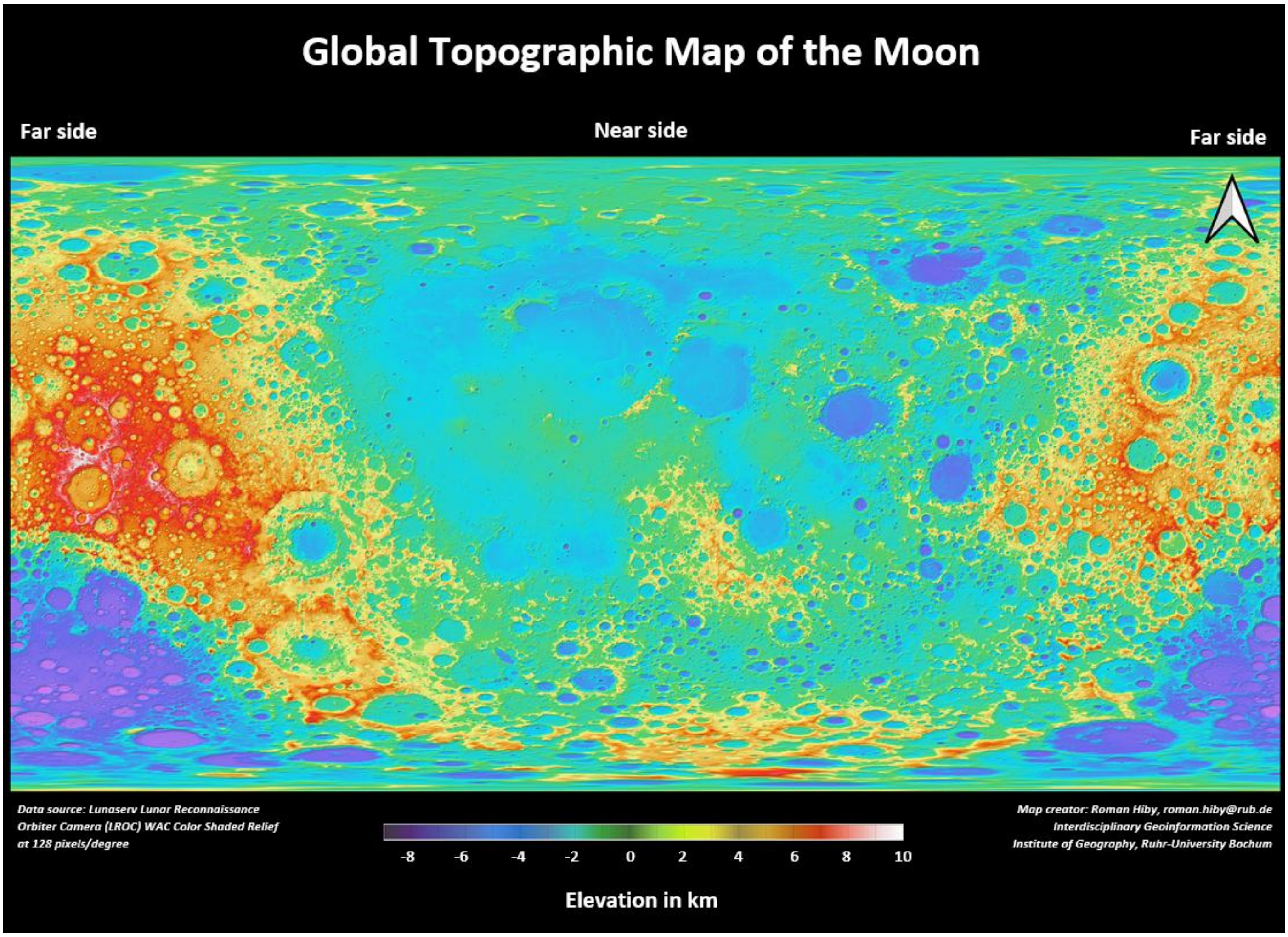

The Earth constantly renews its surface through processes such as plate tectonics (subduction) and weathering. The surface of the Moon, on the other hand, can document its own formation. Unlike the Earth, the traces and scars on the Moon do not disappear.

Samples from the Apollo missions show that, on average, lunar rock is very similar to Earth rock, but there are regional differences. The highland rock is very similar to Earth rock, but the volcanic glass that originated from the magma ocean shows some differences.

Remote sensing also provides fundamental global insights. A large-scale or even global analysis of lunar conditions is simply not possible using ground-based data on the Moon due to the insufficient sample size. This is why the available data sources in the form of satellites on the Moon are so important. The use of lunar observation satellites also offers much better opportunities than satellite observation of Earth due to the absence of an atmosphere and thus weather phenomena, as well as the lower gravitational force of the Moon.

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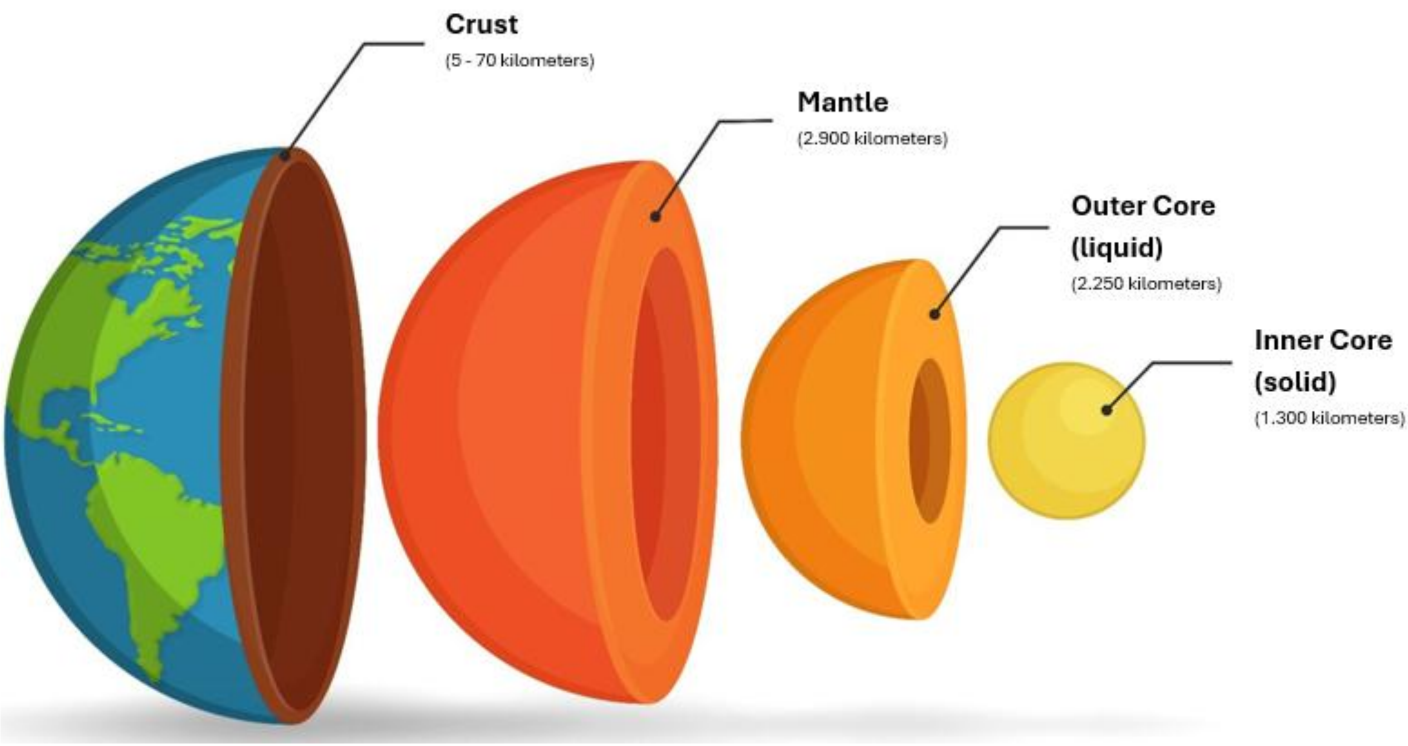
2.2. Compare the density and internal structure of the Earth and the Moon and draw conclusions about the formation of the Moon. Also interpret why the core of the Moon is relatively small. Use the tables, illustrations, and map materials provided. You can also find the maps in 3D in the app.

Average density – Earth	
Crust	**2,2-2,9 g/cm^3**
Mantle	**3,4-5,6 g/cm^3**
Outer Core	**9,9-12,2 g/cm^3**
Inner Core	**12,8-13,1 g/cm^3**
Total	**5,51 g/cm^3**

Average density – Moon	
Crust	**~3 g/cm^3**
Mantle	**~3,5 g/cm^3**
Outer Core	**~5 g/cm^3**
Inner Core	**~8 g/cm^3**
Total	**3,34 g/cm^3**



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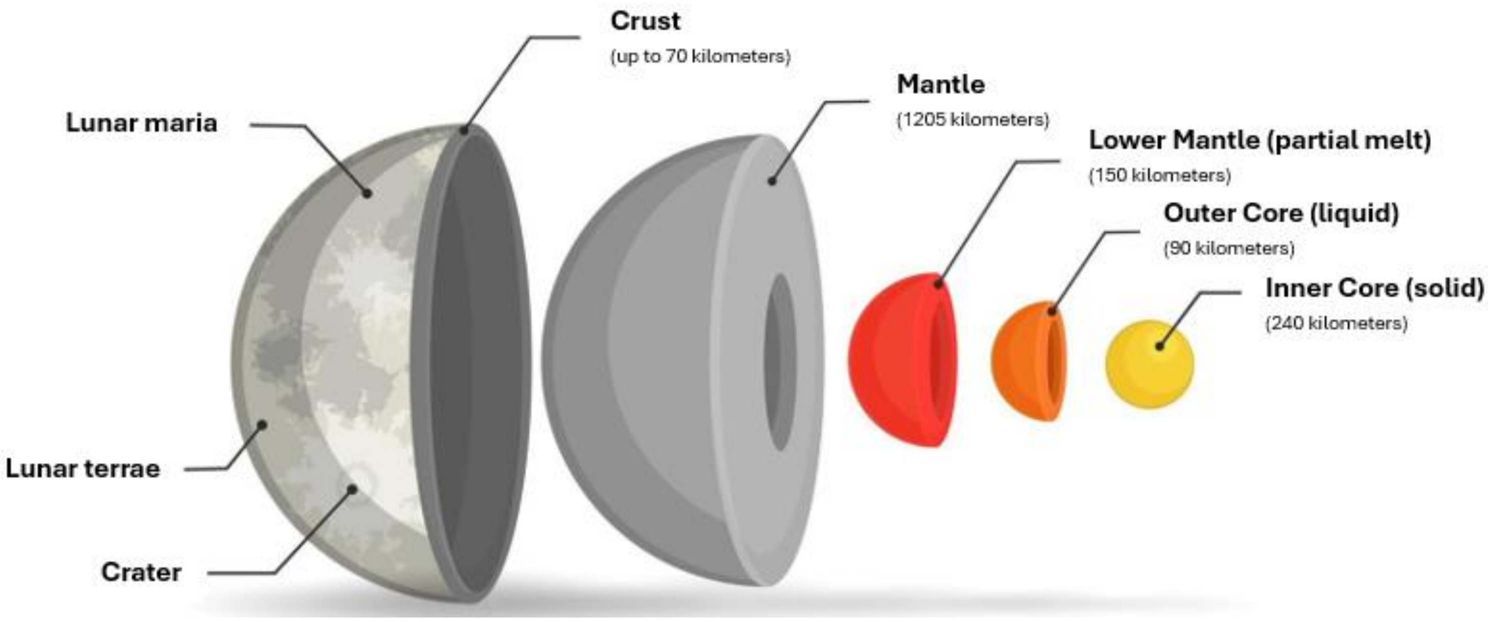

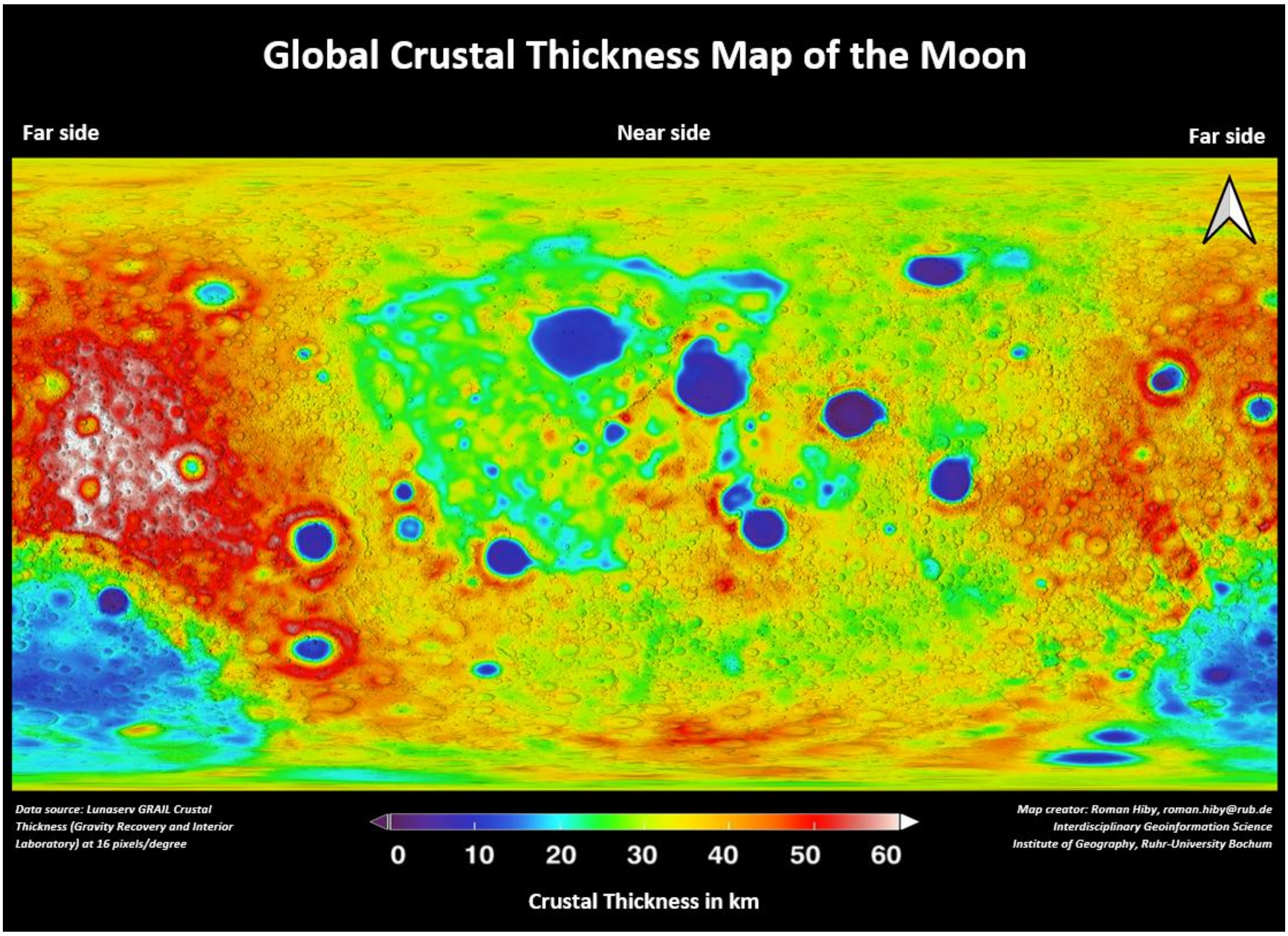

Compile the results so far in a plenary session.

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2.3. Compare the geological composition of the Earth and the Moon and draw conclusions about the formation of the Moon. Use the following table to help you.
Open the Columbus Eye app, find Tranquility Base on the Moon, and read the information text. Identify the conditions prevailing at this point in the available maps and how they differ from global conditions. Also analyze why "*in situ*" data (data obtained on site) is so important for lunar exploration.

The composition of the Moon was estimated based on analyses of numerous rock and soil samples collected during the Apollo missions and supported by remote sensing data. The table shows a comparison of the most important elements of the crust and mantle of Earth and the Moon.

Geological composition of the crust and mantle (in wt%)		
Element	**Earth**	**Mond**
Oxygen	45.2	44.7
Silicon	22.1	22.5
Magnesium	21.9	20.3
Iron	6.0	8.2
Calcium	2.3	2.0
Aluminium	2.1	1.9
Titanium	<1	<1

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Radiometric dating of Apollo rock samples has revealed an age of up to approximately 4.527 billion years. The age of the Moon is determined by dating a few moon rocks based on radioactive decay. To do this, researchers at the University of Münster, Germany investigated the frequency of the isotope tungsten-182 in moon rock. The isotope was formed in part from radioactive hafnium-182, which decays very quickly by geological standards. Therefore, the amount of tungsten-182 can provide a relatively accurate indication of the age of the rocks. This means that our Earth's satellite was born about 30 to 50 million years after the formation of the solar system.

2.4. Explain whether and to what extent conclusions about the formation of the Moon can be drawn from information about changes in the Earth's rotation and the distance between the Moon and the Earth over time.

By measuring the time it takes for a laser beam to reach reflectors on the Moon and return to Earth, scientists have discovered that the Moon is slowly moving away from Earth at a speed of about 3.8 centimeters per year. The reflectors were placed on the Moon during the Apollo missions. At the same time, the speed of the Earth's rotation is slowly decreasing over time. Scientists know how much the Earth's rotation is slowing down from studies of historical solar eclipse observations, fossils, and sediment deposits.

The total energy of the Earth-Moon system remains constant. As the Earth loses energy and slows down, the Moon gains energy, causing its orbital period and distance from the Earth to increase. Scientists can calculate the total energy of the Earth-Moon system by determining the masses of the Earth and Moon, the speed at which they rotate around their own axes, and the distance between them. Since the speed at which the Earth rotates and the speed at which the Moon is moving away are known, scientists can calculate what these values were a long time ago. For example, the diagram shows that about 900 million years ago, the Moon was about 54 Earth radii away, compared to ~60 Earth radii today. At this distance from the Moon, the day on Earth was about 19 hours long; a month had 23 to 24 days, and a year had about 464 days.

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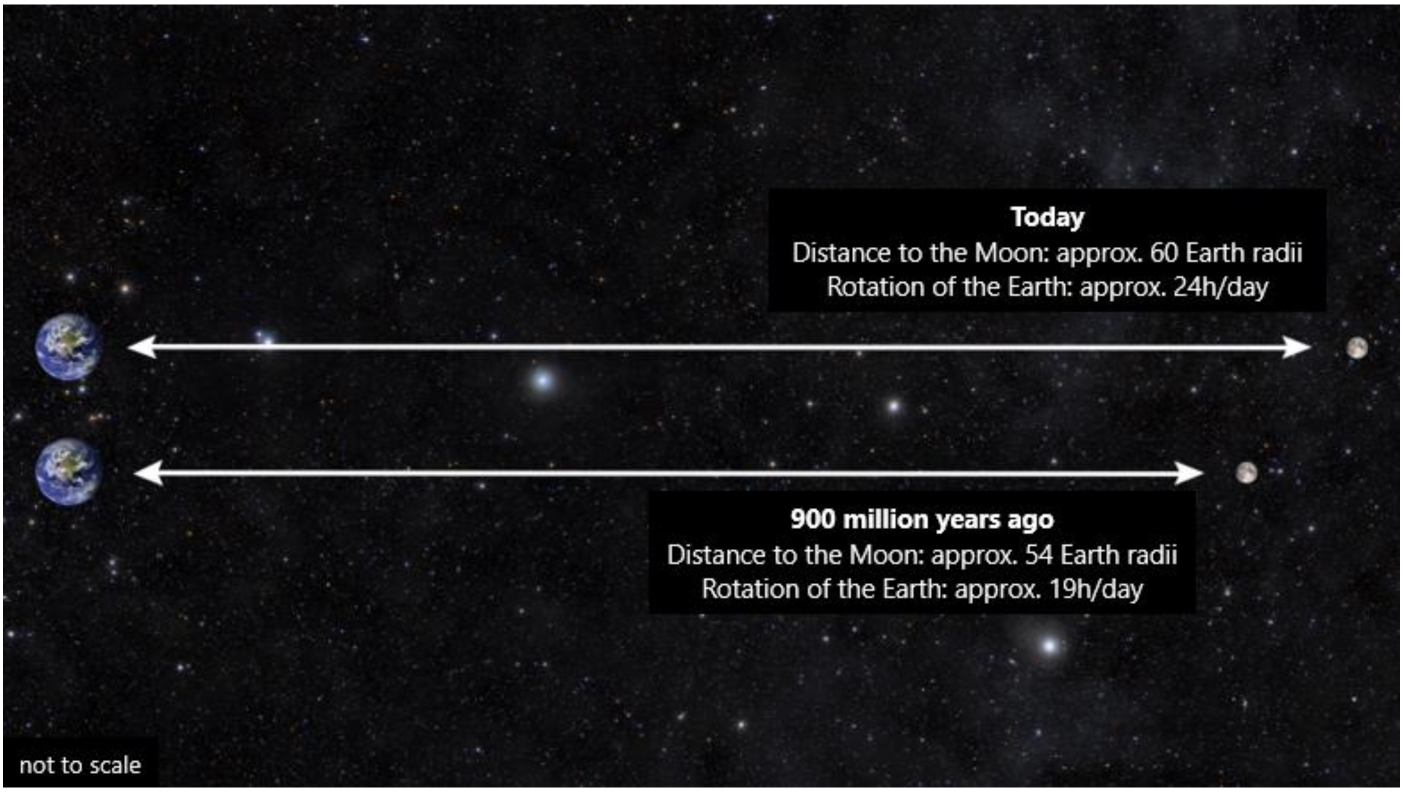

Compile the results so far in a plenary session.

3. Now, in your group, use the evidence to design a **model-evidence link diagram** (see figure). To do this, assess the extent to which certain pieces of evidence support the four different theories. Therefore, you should analyze, how the different evidences support, contradict or have nothing to do with each other. For clarity, the arrows can be drawn in four different colors (for theories 1, 2, 3, and 4).

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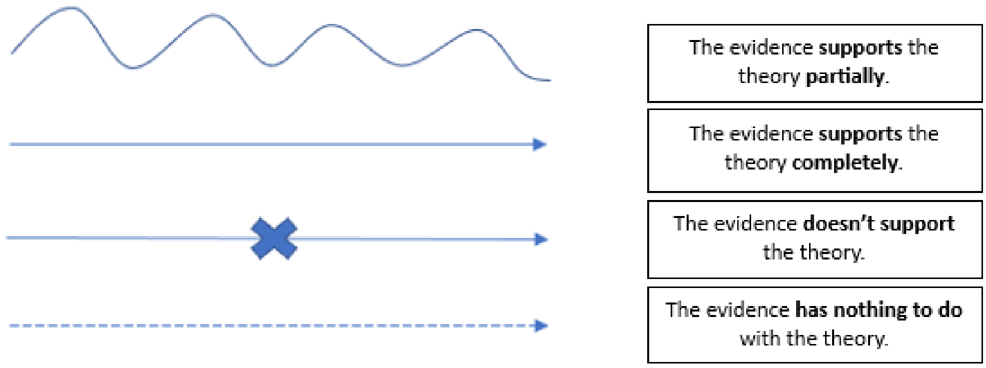

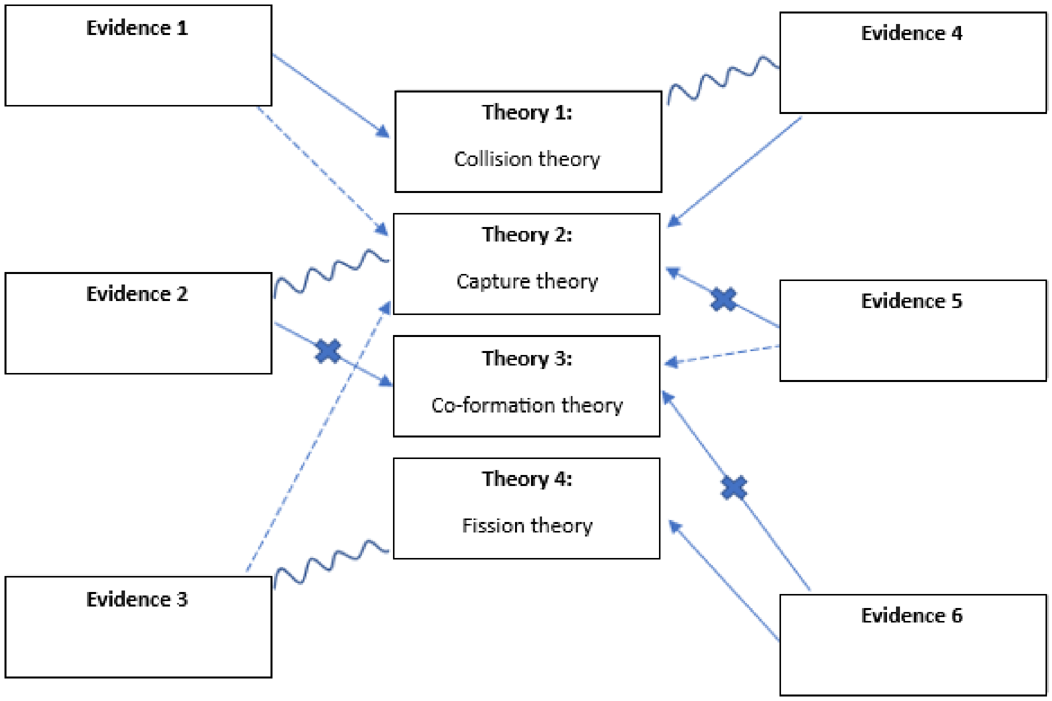

4. Choose three arrows and explain what type of connection arrow you have drawn and why. Select the arrows that you find particularly important or interesting, for example because they have led to disagreements and discussions within the group.

5. Rate the plausibility of the four theories from 1 (very implausible or even impossible) to 10 (highly plausible).

6. Discussion in plenary session

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Additional tasks:

7. Make hypotheses about where the remains of the protoplanet might have disappeared to.

8. Analyze the consequences of the Moon's formation for Earth.

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