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What If the Moon Didn't Exist?

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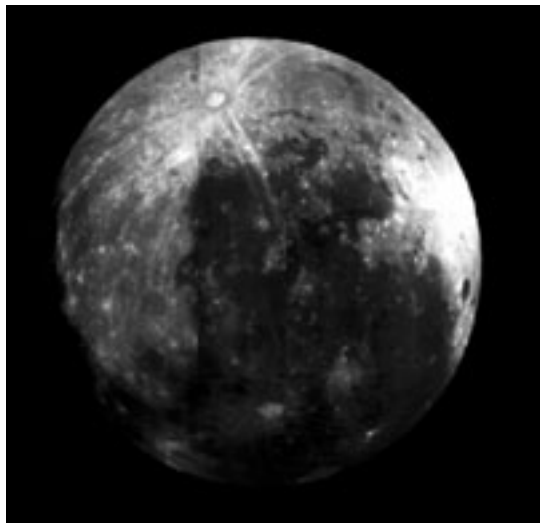
Two years ago, the Clementine space probe snatched this picture of the Moon as lit not by direct sunlight, but by reflected sunlight from Earth. The bright crater near the top is Tycho. Photo courtesy of Naval Research Laboratory.

How many times during the school day do you hear questions of the form, "Well, what if?'' Judging from my oldest son, asking such questions is a common and powerful tool that children use to explore nature and life. Adults play the what-if game, too. The only difference is that we grown-ups do it unconsciously, hundreds of times every day. "What if I don't go shopping today?'' "What if I accept that new job?'' "What if I let Tom have the car tonight?'' Such questions enable us to review our options. Because we are rarely conscious of asking, What if? we do not make as complete use of our conclusions as we would if we actively thought about our thinking.

In 1990, a colleague, David Batuski, came into my office and observed that we science educators are always looking at the world from the same old perspectives. I suggested that we try to look at the world differently. A deafening silence followed for several minutes. After all, it takes a while to inventory all the normal ways one thinks; trying to find alternative viewpoints is indeed a challenge. And then, unexpectedly, my son's what-if questions percolated into my consciousness. It was an epiphany.

"All right,'' I said. "What if the Moon didn't exist? What would the Earth be like?'' We had only a few minutes to discuss it before a student dropped by, but that was enough. I was hooked. Asking such questions and using solid scientific reasoning to answer them lead to incredible insights about the natural world. Between 1991 and 1993, I wrote a series of articles for *Astronomy* magazine exploring a few different changes in Earth's astronomical environment and the likely results of those changes. These articles led to the publication of my book *What If the Moon Didn't Exist? Voyages to Earths That Might Have Been* (New York: HarperCollins, 1993).

How can what-if questions become a catalyst for scientific discovery in the classroom? In what follows, I present a sample scenario, some typical student responses, and a scientific analysis.

Home Alone
Out With the Tide
Tidal Waves
Worse Surfing

Home Alone

In each what-if scenario, I make one change in Earth's environment and then consider the implications of that change. In this example, I form a world identical to Earth -- except that it never acquired a Moon. I call the new world *Solon* to emphasize its solo existence. To understand how Solon would differ from Earth, we need to know how the Moon is affecting Earth today and, working back in time, deduce its effects over the Earth's lifetime. The most obvious effect that the Moon has on Earth is to produce tides (see figure 1). Tides don't just lift boats and uncover clam flats; they have caused profound changes to our world.

Figure 1
Watching the tides roll away. These pictures show low (right) and high (left) tides at Bar Harbor, Maine. The tides are one of the most important ways that the Moon affects life on Earth. They are the result of the fact that the Moon's gravitational pull does not affect all parts of Earth equally: The lunar gravity exerts a stronger pull on the parts of Earth that are closer to the Moon. This tugs the oceans ever so slightly toward the Moon. The effect is small -- it lifts the surface of the ocean by less than 1 meter -- but enough to create a wave that travels around the globe as Earth rotates. As this wave enters shallow coastal waters, it increases in size. Photos courtesy of John Neff, University of Iowa.

Tides occur because the gravitational force between two bodies decreases with distance. Gravitation is the universal force of attraction between all matter. It holds astronomical bodies together and attracts different bodies toward each other. Because gravity tugs on nearby things more strongly than on distant things, the oceans closest to the Moon feel the greatest attraction to the Moon. Being fluid, these nearby oceans move upward in response to the Moon's pull, until there is a balance between the upward force from the Moon and the downward force from Earth. The high tide on the far side of the Earth occurs because these most distant oceans feel the least attraction to the Moon. In essence, they are left behind as the Moon pulls the other parts of Earth toward itself with greater force.

In 1897 George Darwin, son of Charles, suggested that tides are causing the Moon to spiral away from us. His hypothesis was confirmed in 1969 after the *Apollo 12* astronauts placed corner reflectors (like the red and orange ones on a car) on the Moon. By firing lasers from Earth to the Moon, off the corner reflectors, and back again, astronomers measured the round-trip time and, hence, the distance to the Moon. Repeating the experiment over several years, they confirmed Darwin's prediction. The Moon is receding at 2 inches per year.

To understand why the Moon is fleeing from us, imagine for a moment that neither Earth nor Moon rotated and that the Sun's tidal effect could be ignored. In this case, one of the two high ocean tides would be directly between Earth and Moon, while the other would be on the opposite side of Earth from the Moon (see figure 2a).

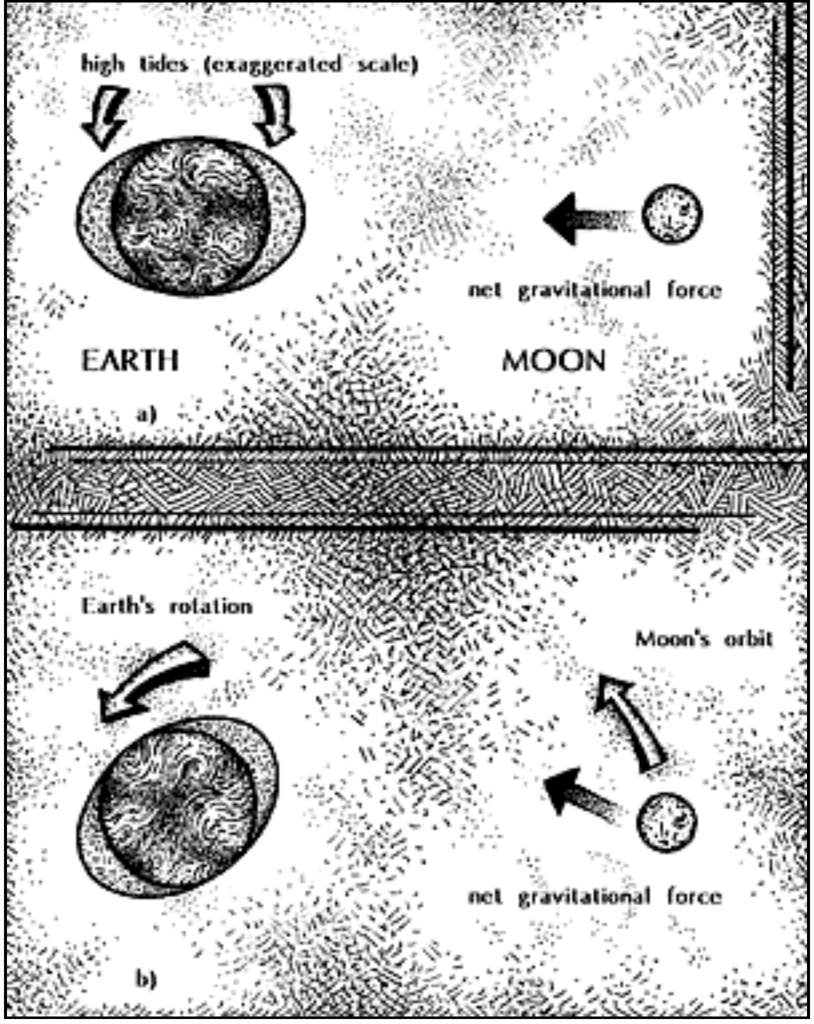

Figure 2

An astronaut's view of ocean tides. This is a much-exaggerated view of the tides as you might see them if you could fly high enough above Earth and Moon. The imbalanced gravitational pull of the Moon causes the oceans to be slightly non-spherical, creating two high tides and two low tides. Of course, the actual tides would be much smaller than shown in these two diagrams.

Suppose, for the moment, that Earth did not rotate (a). In this case, the two high tides would lie on the straight line from the center of the Moon to the center of Earth. The gravitational force would be directly from the center of the Moon to the center of Earth.

Now take a look at what happens on the rotating Earth (b). Because Earth rotates faster (once every 24 hours) than the Moon revolves (once every 29 days), the high tides are not aligned as above. Instead, the rotation pulls the tides around, so that the high tide closest to the Moon outpaces the Moon. This nearer high tide exerts a gravitational force on the Moon, causing the Moon to spiral outward. In return, the Moon exerts a gravitational force on the high tide, causing Earth to rotate slower. Diagram by Kathleen L. Blakeslee.

Now add back the Earth's rotation. Earth rotates in the same direction that the Moon orbits, but Earth spins much faster (once a day) than the Moon goes around it (every 29 days). The rapid rotation causes the high tide to be pulled slightly ahead of the Moon (see figure 2b). This tide gives Earth a handle to crank up the Moon's orbit. The high tide pulls the Moon forward in its orbit, causing the Moon to accelerate and, therefore, to spiral away.
