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What If the Moon Didn't Exist?

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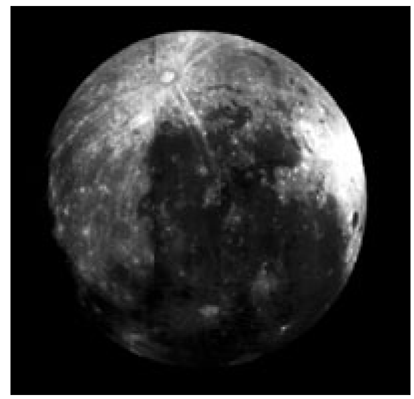

Two years ago, the Clementine space probe snatched this picture of the Moon as lit not by direct sunlight, but by reflected sunlight from Earth. The bright crater near the top is Tycho. Photo courtesy of Naval Research Laboratory.

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

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).

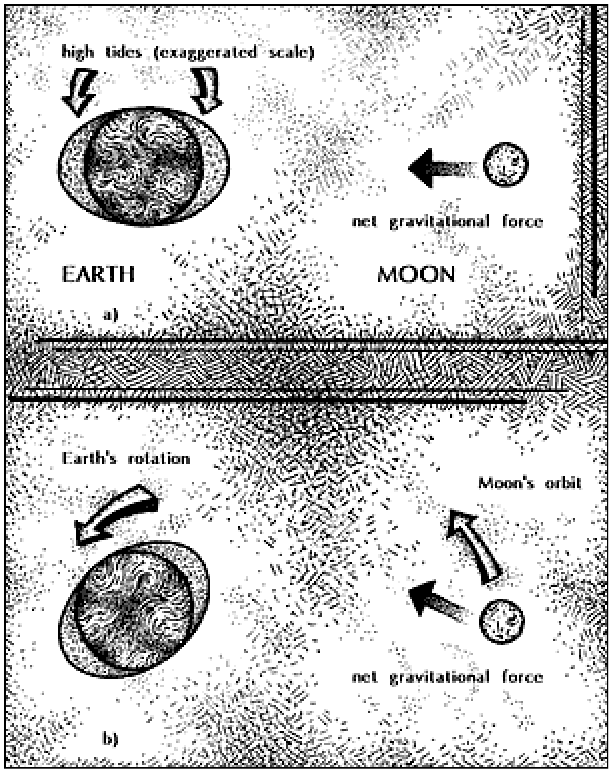

Figure 2

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.

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Out With the Tide

We have a word for things that move farther from Earth: *up*. The Moon is steadily moving up and up. As anyone who climbs long flights of stairs knows, it takes energy to move up. If the Moon is moving up, where does the energy come from? There is only one place it could come from: the spin of Earth. This is a zero-sum game that physicists call the *conservation of angular momentum*: The total angular momentum in the Earth-Moon system, which is related to the energy stored in both rotation and revolution, must remain the same. Since the Moon is gaining angular momentum as it spirals away, Earth must lose the same amount of angular momentum.

Earth loses angular momentum because the high tide closest to the Moon is trying to get back directly underneath the Moon, while the high tide farthest from the Moon is trying to get as far away from the Moon as possible. Consequently, the high tides flow westward, and in so doing, they encounter continents and islands. The water pushes against these land masses, which, because of rotation, are moving eastward. The net result is that the eastward rotation is retarded by the westward motion of the tides -- slowing down the rotation. The day is getting longer by about 0.002 seconds per century. It doesn't sound like much, but over billions of years it adds up.

If Earth is slowing down, it must have been rotating more rapidly in the past. By counting the growth rings in 400-million-year-old coral fossils and in 3-billion-year-old stromatolites, geologists calculate that Earth was rotating four times faster when it formed than it is today. The tidal effects of the Moon and, to a much lesser degree, the Sun have lengthened the day from six hours to 24 hours.

We can also work backwards in time for the Moon. Since the Moon is moving away, it must once have been closer. The closest the Moon could have been was about 7,300 miles above Earth's surface, 1/20th its present distance -- any closer, and the tides created on it by Earth would have ripped the Moon apart, turning it into a ring. This limit on the Moon's distance is consistent with the theory of how our satellite formed.

The Moon did not form with Earth. The chemistry of the Moon's rocks and other evidence indicate that the Moon was once part of Earth. When a huge asteroid hit Earth early in our planet's history, a huge volume of rock literally splashed into orbit. The young Earth had been a parched, steaming world of volcanoes and oozing rivers of molten rock, with an unbreathable atmosphere of carbon dioxide and virtually no surface water -- in short, an inhospitable, lifeless world. The impact shattered Earth's tenuous crust, sending superheated gas and water vapor out into interplanetary space. At the same time, large quantities of the Earth's mantle and crust (its outer layers) went into orbit around our planet. This material quickly coalesced into the Moon. This impact has been reproduced successfully in computer simulations.

Tidal Waves

Let's assume that the Moon formed 10 times closer to us than it is today. In this case, the tides on the young Earth were 1,000 times higher than they are today, since tidal forces vary inversely with the cube of the distance. These humongous tides plunged miles inland and withdrew every three hours (remember, the day was only six hours long). As they moved over the land, the awesome volumes of water scraped and pounded the primeval rock, removing and pulverizing a considerable amount of it. Every time the tide retreated, it dragged this material back into the ocean. Continually churned up in the water, these chemicals formed the broth in which life probably formed.

With this information as background, we are ready to consider what Solon, a moonless Earth, would be like:

The length of the day

On Solon, the only tides would be from the Sun. The Sun accounts for one-third of the tides on Earth today. Therefore, Solon would still experience some tides and its rotation would still slow down, but not nearly by as much as Earth's. Solon's day would be around eight hours long at this time in its life, 4.6 billion years after it formed.

Winds

The faster a planet rotates, the faster its winds blow. We see the effects of extreme rotation by looking at Jupiter, which rotates every 10 hours. There, the winds are pulled into east-west flowing patterns, with much less north-south motion than occurs on today's Earth (see figure 3). Furthermore, the wind speeds on Jupiter are typically between 100 and 200 miles per hour. This indicates that the winds on Solon would flow more east-west than they do on Earth and that their speeds would be much higher. Winds of 100 miles per hour would occur daily, and hurricanes would have even higher wind speeds.

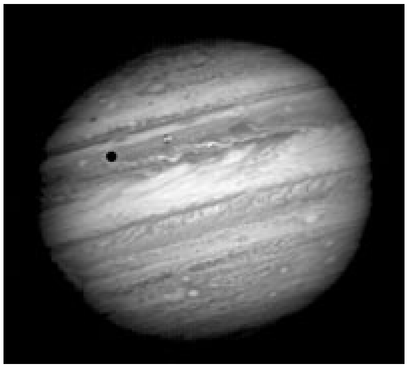

Figure 3
Jupiter, as seen by the Hubble Space Telescope. The dark circle on the upper left of the jovian disc is the shadow of the innermost jovian moon, Io, seen to the right of the circle. As Jupiter spins once every 10 hours, it drags its outer atmosphere with it -- creating high winds that blow east-west around the planet. These winds are highlighted by the dark belts and light zones that gird the gas giant. The winds have only a limited north-south motion. Photo courtesy of Harold A. Weaver and T.E. Smith, Space Telescope Science Institute; John T. Trauger and R.W. Evans, Jet Propulsion Laboratory; and NASA.

Origins of life

The high lunar tides filled Earth's early oceans with the chemicals necessary for life to evolve under the influence of the Sun's radiation. While Solon would experience the same radiation, its oceans would fill at a snail's pace with the chemical building blocks of life. The paltry tides on young Solon would contribute little to enriching the oceans. The primary way that chemicals would enter the ocean would be through river flow. We see the same thing happening today at the mouths of rivers, but the rate is very, very slow compared to the effects of monster tides. Therefore, it would have taken longer for a critical mass of chemicals to fill the oceans. As a result, it would likely have taken much longer for life to evolve.

Biological evolution

Both the higher winds and the shorter days on Solon would have major effects on evolution. The winds would mediate against tall life forms that are not stabilized by their weight, broad bodies, or deep roots. Palm trees are a good example of a life form unlikely on Solon: These trees have shallow root systems and are easily knocked down by strong winds.

Tree-dwelling life would have a more difficult time on Solon, since tall trees there would sway more than they do on Earth. This does not necessarily mean there would be no ape-like creatures. Rather, it means that such creatures would have to be even more responsive to their environment than arboreal creatures on Earth. This could actually lead to even more complex brains in Solon's tree dwellers and, perhaps, different mental capacities.

Try to imagine what day-to-day life would be like with only three or four hours of sunlight each day. For one thing, life forms would evolve biological clocks with different cycles than those on Earth. Many activities of terrestrial life forms are regulated by internal biological clocks: Waking, sleeping, hunger, and mating depend on the circadian rhythms. Studies have shown that biological clocks in most creatures do not cycle in exactly 24 hours. For example, the dominant human circadian rhythm has a 25-hour cycle. Fortunately, sunrise resets, or entrains, clocks that are not precisely 24 hours long. But entraining can only occur if a biological clock is within three hours of the day-night cycle. On Solon, with its eight-hour day, animals possessing Earth-like biological clocks would quickly get out of sync. They would be sleeping when they should be awake, hunting when they should be mating, and so on. They would become vulnerable to attack by better-adjusted predators.

What If the Moon Didn't Exist?

Worse Surfing There are many other differences between Earth and Solon that your students can discover, and there are innumerable other alternative Earths, several of which are in my book. Let me now turn to one way that I have effectively used what-if questions in grades 4-12 and college.

I normally begin by asking the class what they think would be different if the Moon didn't exist, or if the Sun were closer to Earth, or if a star exploded nearby. Here are common replies to the question, "What if the Moon didn't exist?''

- No tides (not true)
- No intertidal zone (not true)
- No eclipses
- Darker skies for astronomy
- Some animals affected (such as salmon and turtles)
- Different night creatures
- No gravity (not true)
- More impacts on Earth by space debris
- No lunar calendar
- No lunar phases
- Worse surfing
- Darker nights
- Different name for "lunatics''
- No lunar fables (werewolves and so on)
- No nearby place for astronauts to go
- A lost vehicle for romance
- A lost theme for love songs
- No Man in the Moon

After acknowledging these ideas, and correcting the wrong ones, such as the disappearance of tides, I present the major astronomical results:

1. The day would be eight hours long.
2. The winds would be much stronger.
3. Complex life might not exist yet.
4. When life did arrive, it would have a different biology.

By seeing these results up front, students begin to rethink their ideas to make sense of this new information. This is often disconcerting for them, but they are eager to understand how these ideas might be correct. Then I proceed to work through the properties of Solon described above.

I was delighted to learn that many middle-school and high-school teachers around the country are using *What If the Moon Didn't Exist?* to help to teach about Earth and space. Such projects are usually done in groups of three or four. It is useful to ask students specific questions about the alternative Earth. For example, "How would the temperature be different if the Sun were more massive?'' "What would happen to humans if the ozone layer were depleted by 25 percent?'' John Hilker in Union, Maine has his students explore such what-if questions; the scenarios they create are put on computer and videotaped. Hilker has offered to field your questions about this work. You can reach him at the A.D. Gray Middle School, P.O. Box 329, Waldoboro, Maine 04572.

In my college introductory astronomy course, I require students to write a short (2,000-word) term paper that does one of three things: explain in more detail (or even try to disprove) the science in one of the chapters of my book; extrapolate a scenario in a direction that I did not take it; or ask a new what-if question and explore some of its implications.

In using what-if questions in the classroom, it is worth bearing in mind that students extrapolating the effects of new scenarios will encounter two different situations: direct changes to the new version of Earth and indirect changes resulting from the direct changes. Direct changes result from the astronomical variation, such as Solon's more rapid rotation and lower tides. More challenging are the indirect changes, such as higher winds, slower evolution rate, faster biological clocks, and need for sturdy support against strong winds. Many secondary changes create other changes in turn, a hierarchy that can be explored with concept maps or flow charts.

To elicit ideas about indirect changes, I ask questions about the effects of the direct changes on specific things that exist today. For example, "What effect would the high, sustained winds have on oral communications on Solon?'' Well, we know from experience that high winds make speaking and listening hard. Therefore, maybe speech would not evolve on Solon. Perhaps an organ that changed colors or moved like a semaphore flag would become the preferred method of communication for advanced life forms, or who knows?

By making students aware of the power of asking, What if? we give them another intellectual tool to help them to cope with an increasingly complex world.

NEIL F. COMINS is a professor of physics and astronomy at the University of Maine in Orono. He is author of *What If the Moon Didn't Exist? Voyages to Earths That Might Have Been* and *Discovering the Universe* (fourth edition, with W.J. Kaufmann III). His email address is galaxy@maine.maine.edu.