Did Einstein really prove that Newton was wrong?

It is widely believed that Einstein proved that Newton's classical mechanics was wrong. But, was it really wrong? If it was really wrong, how could scientists believe in the wrong theory for over two hundred years? If it was really wrong, is Newton's classical mechanics useless? If it was wrong, are the claims that Newton successfully explained many phenomena sheer lies? If Newton's theory was wrong, are there any chances that Einstein's theories eventually turn out to be wrong as well? If Einstein's theories are also wrong, and every theory eventually turns out to be wrong, what is the point of theories in physics?

In this essay, I will try to answer these questions and explain how physics develops. To understand these questions more easily and fully, I will begin with similar precedents in the history of astronomy.

Ancient people believed that the Earth was flat and something below it was supporting it. For example, Indians believed that the Earth was supported by elephants on a turtle. Ancient Egyptians and Babylonians thought that the Earth was a disk floating on the ocean.

So, why did they think so? From the days of Adam and Eve, every human being knows that every object falls downward. They thought, "if everything falls downward, and if the Earth is not flat, but round, people living on the opposite side of the Earth will fall downward, that is, to the sky." They thought, "if everything falls downward, and if nothing props up the Earth, the Earth will fall down, too. However, we know that the Earth is not falling. Otherwise, we would have noticed it. So, something must be propping up the Earth."

If you didn't receive any elementary school education, you may find nothing wrong with their arguments; they would sound very plausible to a four-year-old kid. I would have agreed with their views if I hadn't received any elementary school education. And, even in modern days, some people have the same views as these ancient people, even though they received enough education to use computer graphics to edit videos to upload on Youtube, which I am not utterly incapable of.

Most people these days are familiar with the fact that the Earth is round because we are so used to seeing the globe (i.e., a small model of the Earth), and many people are taking overseas trips by airplane. But, how, how, would you figure out that the Earth is round and is not propped up by anything, two thousand five hundred years ago? That is, two thousand years before Magellan made the first around-the-world trip.

I used to think that the breakthrough regarding the shape of the Earth was made when ancient scientists figured out that the shape of the Earth was round. However, when I closely looked into "Anaximander," a book on the ancient Greek astronomer, I changed my mind. Actually, when I read its first pages, I found it so boring that I had to stop reading it. Later, when I was reading another book to write articles on the history of astronomy, I had to consult this book again to learn more about the Greek astronomer, who was mentioned in the book that I was reading. When I read one of the middle chapters of "Anaximander," I found it amazing. I learned that I should never judge a book by its first pages. I ended up reading the whole book immediately.

The book is written by Carlo Rovelli, not a historian of science, but a physicist who discovered loop quantum gravity with his collaborator, Lee Smolin. He is currently one of its main leaders. According to him, Anaximander was the one who made the first real breakthrough regarding the shape of the Earth.

Anaximander thought that the Earth was a cylinder, which every educated elementary school student now knows to be far from being the true shape of the Earth; the Earth looks like a ball. Then, how can we say that he made the first breakthrough?

It's because he was the first one who figured out that the Earth did not need anything to prop it up. In other words, contrary to others before him, he thought that there was "sky" below the Earth. OK. Why did he think so? What kind of evidence did he have?

Rovelli says that there is much evidence for this idea. The Sun sets in the West, but it rises in the East the next day. It must have passed through the sky below the Earth. If we look at the stars the case is clearer. We see stars revolving around the North Star completing a circle approximately in twenty-four hours, except when they are invisible, blinded by sunlight during the day. See the photo, which was taken by a long exposure time. The arcs are the trajectories of the stars. You see that some trajectories are partially covered by the Northern mountains. If there were no Northern mountains, we would have seen connected trajectories. We can be sure that the stars didn't actually disappear and were re-created again, but they just hid behind the mountains for a while. Notice also that bigger arc trajectories are covered by the ground. Thus, we can again conclude that the stars just hid behind the ground for several hours. This means that there is space below the ground.

Taken in Chile's Atacama Desert by ESO Photo Ambassador Adhemar M. Duro Jr.

Rovelli goes on to explain that this reasoning may sound very easy, but it is very hard to catch for the first time. For example, despite their great ancient civilizations, the Chinese didn't catch this before the Jesuits came to their country in the 16th century and taught them Western astronomy. It is too hard to believe that the Earth floats in space, considering that every object falls. Rovelli says "we must accept that the world may not conform to our direct experience and to our long-held image of it, that things may be other than they seem and from the way everybody has always thought they are."[1]

Rovelli goes on to explain Anaximander's argument on why the Earth doesn't need to fall. We think that everything falls downward. However, the notions of directions such as downward or upward are meaningless, if the Earth is at the center. Let me clarify. See Fig. 1. If there is a true notion of "downward," and the Earth is supposed to fall "downward," it's a privileged direction; of all the directions, a direction is singled out. Why should such a direction exist in our Universe? There is no reason why the Earth should fall in that particular, arbitrary direction. Now, let's consider the case in which such an arbitrary direction is not singled out. See Fig. 2. If the Earth is at the center, and if "downward" is towards the center, no direction is singled out. The Earth doesn't need to "fall," because there is no preferred direction to fall. It can just stay there.[2] This reasoning is ingenious as Aristotle, who originally explained Anaximander's argument, indeed noted.

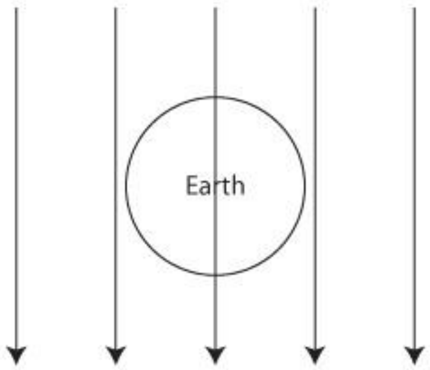

Fig. 1. A direction is singled out

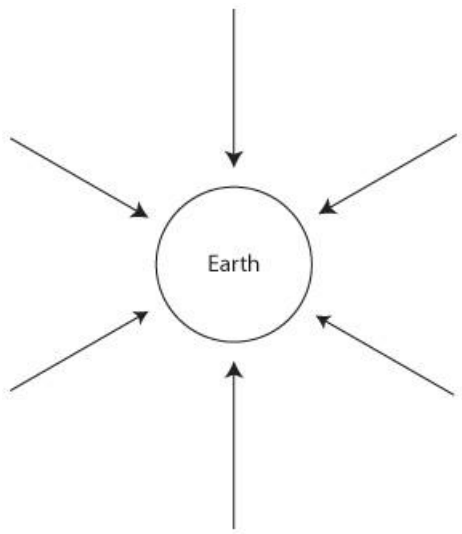

Fig. 2. No direction is singled out

Rovelli also remarks that the Earth is not a cylinder, but more like a sphere. He further remarks that

[1] p52, "Anaximander" by Carlo Rovelli.

[2] Rovelli notes that Fig. 2 may not necessarily be the shape of the Earth Anaximander imagined, but also notes that the important point is that Anaximander pointed out that Fig. 1 was a wrong model.

the Earth is not actually a sphere, but more like an ellipsoid, flattened at the North Pole and the South Pole. Then, he remarks that it is not a true ellipsoid either because the South Pole is more flattened than the North Pole. Then, he remarks that there are additional irregularities.

Now, back to our original story. In a strict sense, it is true that Newton's classical mechanics was wrong. Nevertheless, it would be fair to say that Newton's classical mechanics was a very good theory, which successfully explained many phenomena not only qualitatively but also quantitatively.

To better understand what I mean, let me give you an analogy. Suppose you want to find the shortest distance from Seoul to Boston. If you model the Earth as a sphere and calculate the distance, you will obtain a value very close to the real one, actually within 0.5%, considering that the distance from the center of the Earth to the North Pole or the South Pole is only about 0.3% smaller than the distance from the center of the Earth to the equator. The Earth is indeed a sphere if we ignore errors of less than 0.5%. Of course, if you want to find the shortest distance from Seoul to Boston correct within 0.1%, you definitely need to consider the "ellipsoid" effect. In such a case, the calculation is much more complicated. Nevertheless, if you allow a 0.5% error in the value for the distance, you don't need such trouble.

Similar statements can be made about the relation between Newton's classical mechanics, and Einstein's theory of relativity. When the objects move at speeds quite negligible compared to the speed of light, and gravitational forces are not immensely strong, you do not need to consider the "relativistic" effect as long as your apparatus is not sensitive enough to measure the difference that such a relativistic effect would make. By not considering such a relativistic effect, you can also save much of your trouble. The calculation based on Newton's classical mechanics is much easier than the relativistic one. However, when the objects move very fast or gravity is immensely strong, and you need high precision, you cannot neglect the relativistic effect; Newton's classical mechanics is clearly "wrong" for such a purpose.

Nonetheless, we can as well say that Newton's classical mechanics is "right" in its proper domain. In my essay "the mathematical beauty of physics," I already explained that "every new theory in physics must be able to explain new phenomena in addition to describing old phenomena that an old theory has already explained adequately." This is applied to our example as well; it can be mathematically shown that Einstein's theory of relativity makes the same predictions as Newton's classical mechanics does when objects move slowly and the gravitational forces are not immensely strong; the relativistic effect becomes negligible. We say Einstein's theory of relativity "reduces to" Newton's classical mechanics in such limits. In the domain in which Newton's classical mechanics is right, Einstein's theory of relativity is also right. Indeed, Nobel laureate Max Born said: "The continuity of our science has not been affected by all these turbulent happenings, as the older theories have always been included as limiting cases in the new ones."

On the other hand, as much as the theory that the shape of the Earth is ellipsoid is neither the final nor precise theory, Einstein's theory of relativity is in turn neither the final nor precise theory either. In the 19th century, physicists discovered some phenomena that can never be explained in the framework of the classical theory. In 1925 and 1926, Heisenberg and Schrödinger discovered "quantum mechanics" which can explain such phenomena; the law of physics should be modified for the microscopic (i.e., very small) world. In 1926, Dirac generalized Heisenberg's formulation of quantum mechanics and showed how to apply the "quantum principle" to any given classical (i.e., non-quantum) theory. This quantum principle must be always taken into account in the microscopic world. It also means that Einstein's theory of relativity needs to be re-written in a language that is consistent with the quantum principle because it can never be a correct theory in the microscopic world otherwise. Loop quantum gravity and string theory do this job. They describe Einstein's theory of relativity in a way compatible with the quantum principle. Of course, it is also possible that they are not also the final theories themselves but mere approximations of more fundamental theories.

Each replacement of an old theory by such a new theory requires a fundamental re-thinking of concepts and ideas. Einstein's theory of relativity broke the naïve notions that time flows at the same rate for everyone and that our spacetime is flat. Loop quantum gravity broke the notion that the geometry of our space is smooth, and proposed instead that there are minimum units for space, which means that our space is not infinitely divisible.

This is somewhat in contrast to the development of the understanding of the shape of the Earth, in which the transition from the spherical Earth to the ellipsoidal Earth or from the ellipsoidal Earth to the Earth more flattened at the South Pole, didn't require a big conceptual jump. Only Anaximander's model of the Earth (and perhaps the transition from the cylindrical Earth to the spherical Earth) can be regarded as the true conceptual jump.

Even though conceptual jumps are needed in new theory, and the approach in the new theory may be quite different from the approach in the old theory, the lesson we have learned in the old theory is never discarded. In most cases, the old theories serve as stepping stones for the new theories, and in all cases, they serve as touchstones for the new theories as physicists need to check that the new theories reduce to the old theories in their proper domain. In a loop quantum gravity lecture, Carlo Rovelli said,

"We don't unlearn what we have done. [...] Of course, it's hard to pinpoint exactly what is the key thing that remains with us, but science is about adding knowledge and interpreting previous knowledge, but it's not about discarding previous knowledge."[3]

[3] Introduction to Loop Quantum Gravity - Lecture 1: The empirical basis of quantum gravity

Two comments. First comment. It seems that some people think that there is no objective truth, as Newtonian mechanics was proven "wrong" by Einstein's theory of relativity, and Einstein's theory of relativity is proven "wrong" by quantum gravity theories such as loop quantum gravity and string theory, which may be proven "wrong" again in the future. I am sure that you would understand where their misunderstandings lie if you have carefully read this essay so far. Even though they were proven "wrong," they are "true" within their domains of validity. Moreover, as each theory is replaced by a new one, the domain of validity is widened. As physics progresses, we are certainly approaching the "absolute truth" which may exist or may not exist. And, I don't care even if such an absolute truth doesn't exist, as long as we are constantly approaching it. For the same reason, I don't care what the *exact* shape of the Earth is either. An *approximate* shape of the Earth is enough, as long as it is indeed enough. I will never get to measure the shape of the Earth in errors less than the size of atoms. Moreover, if an ant passes by and displaces a grain of sand, the *exact* shape of the Earth will change. On the other hand, approaching the absolute truth in physics is much more fun than learning the exact shape of the Earth, as each step of the former requires conceptual rethinking while the latter doesn't. Furthermore, when expressed in our *everyday language*, epistemological truths such as conceptual ideas and principles seem to be always proven wrong by new theories, heading *nowhere*. To repeat Rovelli's quote, "it's hard to pinpoint exactly what is the key thing that remains" as each theory is replaced by a new one. However, if you calculate what new theories predict, we are heading *somewhere*, approaching more and more accurate values and their domain of applicability widens.

Let me give you three examples. First example. In the case when the air resistance is negligible, do objects with different densities fall at different speeds? Ancient people, including Aristotle, thought so. An object with a higher density seems to fall faster than an object with a lower density. However, Galileo Galilei proved that they fall at the same speed by his famous experiment at the Tower of Pisa. So, the naïve, experimentally unsupported expectation of the ancient people was proven wrong. On the other hand, I showed that Verlinde gravity predicts that objects with different densities must fall at different speeds even when the air resistance is negligible. If experimentally verified, this would mean that Galileo Galilei was in turn wrong again. Assuming Verlinde gravity was proven correct, does this mean that ancient people were right, and Galileo Galilei was wrong? Probably. Does this mean that ancient people were closer to the truth than Galileo Galilei was? This is an absolute "No." Ancient people expected that an object with higher density would fall significantly faster than an object with lower density. However, according to my calculation, Verlinde gravity says that objects with different densities fall almost at the same speed but at just very

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https://www.youtube.com/watch?v=Mp4fpwl9loQ&

slightly different speeds; if you drop an aluminum ball and a gold ball simultaneously at the Tower of Pisa, the gold ball will reach the ground just 0.000000000007 seconds faster. Indeed, if expressed in our everyday language, physics seems to head *nowhere*, renouncing an earlier position to go back to an even earlier position. However, if expressed in the language of mathematics, and calculated quantitatively, physics is heading *somewhere*, the absolute truth, which may or may not exist, but is a concrete destination to be *headed*.

Second example. Most, if not all, ancient people perhaps believed that, if the Earth is indeed rotating at such a high speed, the motion of objects on the Earth, such as falling stones or flying arrows must be affected by it. However, as they never perceived such effects from their experience, they firmly believed that the Earth was not moving. Nevertheless, Galileo Galilei argued that such reasoning by ancient people was wrong; if someone drops a stone at the top of the mast of a moving ship, it will land right below the mast instead of a spot behind. This is a valid argument. However, it is not true that the rotation of the Earth does not affect the motion of objects. The rotation of the Earth causes what is called the "Coriolis effect." "Coriolis force" bends the path of moving objects. The Coriolis effect may not be quite noticeable in our everyday lives, such as falling stones or flying arrows, but it has a great impact on objects with fast and big scales, such as typhoons. For example, a typhoon rotates clockwise in the Northern hemisphere, and anti-clockwise in the Southern hemisphere due to the Coriolis effect. Coriolis force bends the wind. Also, Coriolis force must be taken into account when firing a missile. Again, the truth Coriolis found was closer to Galileo Galilei's than the naïve intuition the ancient people had, even though it would suggest otherwise if put in the language of everyday life instead of the language of mathematics. If you, a layman, ask whether the rotation of the Earth affects the motion of objects on the Earth, the expert's answer is "yes." But, upon hearing this answer, you will probably think that the expert meant that, if you drop a ball, it will land west, as the Earth rotates from west to east. However, it actually lands slightly *east* because of the Coriolis effect, i.e., because of the rotation of the Earth.[4] For example, if you drop a ball from the top of the Eiffel Tower (324 meters in height) it will take about 8 seconds to drop during which the ground where the Eiffel Tower is located moves about 2.5 km eastward due to the rotation of the Earth. However, the ball doesn't land 2.5 km west, but about 8.5 cm east. If we use the language of mathematics, we can avoid such misunderstanding the laymen would have had, in the first place, and clearly explain why and how far it lands west.

Third example. In the late 17th century, Newton asserted that there was absolute space and absolute time, while his contemporary Gottfried Leibniz asserted that there were no such things. Gottfried argued that space doesn't have any meaning if no objects have been placed, and it has a meaning

[4] In our later article "Coriolis force" you will learn why.

only in relation to the distances between objects placed. He argued that time has no meaning if objects don't move. Actually, the concept of absolute space and absolute time was the foundation of Newtonian mechanics. However, in the late 19th century, Michelson and Morley showed that the motion of the Earth doesn't affect the speed of light. If there were absolute space, the speed of light would have been affected by the motion of the Earth relative to the absolute space. But no such effect was ever observed. That there is no absolute space and absolute time was the foundation of Einstein's theory of relativity. Indeed, Einstein's prediction that time can pass by at different rates for different observers was not only qualitatively, but also quantitatively confirmed to high precision. However, the Cosmic Microwave Background Radiation, loop quantum gravity, and Verlinde gravity seem to suggest that there indeed is an absolute space and absolute time.[5] How each of them suggests so is subtly different, which I would not elaborate on here. Anyhow, some argue that loop quantum gravity and Verlinde gravity are wrong, as they break the notion of relative space and relative time supported by Einstein's relativity. Nevertheless, I can never agree with them considering that epistemological truths, when expressed in our everyday language, have been proven wrong many times. In any case, my point is that the notion of relative space and relative time according to Einstein is closer to the absolute truth, our destination than the notion of absolute space and absolute time according to Newton, even though modern science seems to suggest that there are absolute space and absolute time instead of relative space and relative time. Confused philosophers, who cannot follow even the simplest relativity calculations or loop quantum gravity calculations, may have a hard time understanding it.

Second comment. So far, we have seen that old theories which are right in their own domains are wrong in more extended domains. As explained in my article "The mathematical beauty of physics," despite being "wrong" they are still important in formulating new theories that are right in more extended domains.

On the other hand, it sometimes happens that theories that are wrong even in their own proper domain of validity serve themselves as stepping stones for correct theories in their own proper domain. For example, Rayleigh derived the blackbody radiation spectrum in May 1905. Jeans found a mistake in Rayleigh's derivation in June; it was off by a factor of 8. Even though Rayleigh was wrong, Jeans would have a much harder time deriving what is now called ``Rayleigh-Jeans law" without the wrong calculation by Rayleigh.[6] He would have had to take the steps Rayleigh did,

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[5] Perhaps, "preferred" space and "preferred" time are better words.

[6] Actually, Rayleigh-Jeans law is satisfied only for long wavelength, and Planck's law is correct for all wavelength range. But that is a different story. Here, I mean that Jean's calculation was wrong even in its proper, potential domain which is long wavelength range.

again.

A similar remark can be made about my role in loop quantum gravity. As mentioned, loop quantum gravity predicts that there are minimum units for an area. Traditional loop quantum gravity can calculate the values for the minimum units of area. However, I showed that their calculation was wrong. I showed that they should be given by the square root of the values they have calculated. However, without the wrong, old loop quantum gravity, I would have never succeeded in calculating the correct values for the minimum units of area.

The photo is from https://www.eso.org/public/images/potw1631a/