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The Limits of Science

Does science have outer limits? Where are the boundaries of the universe, and what lies beyond them? What will the end of science entail?

Schema huius præmissæ diuisionis Sphærarum.

Scheme of the division of the celestial spheres, a drawing from the publication by Petrus Apianus and Gemma Frisius, *Petri Apiani cosmographia, per Gemmam Phrysium, apud Louanienses medicum ac mathematicum insignem, restituta: additis de adem re ipsius Gemmae Phry. libellis, ut sequens pagina docet*, Antwerp 1539. Source: Edward Grant, "Celestial Orbs in the Latin Middle Ages," *Isis*, Vol. 78, No. 2 (1987), pp. 152–173, cited after Wikimedia Commons

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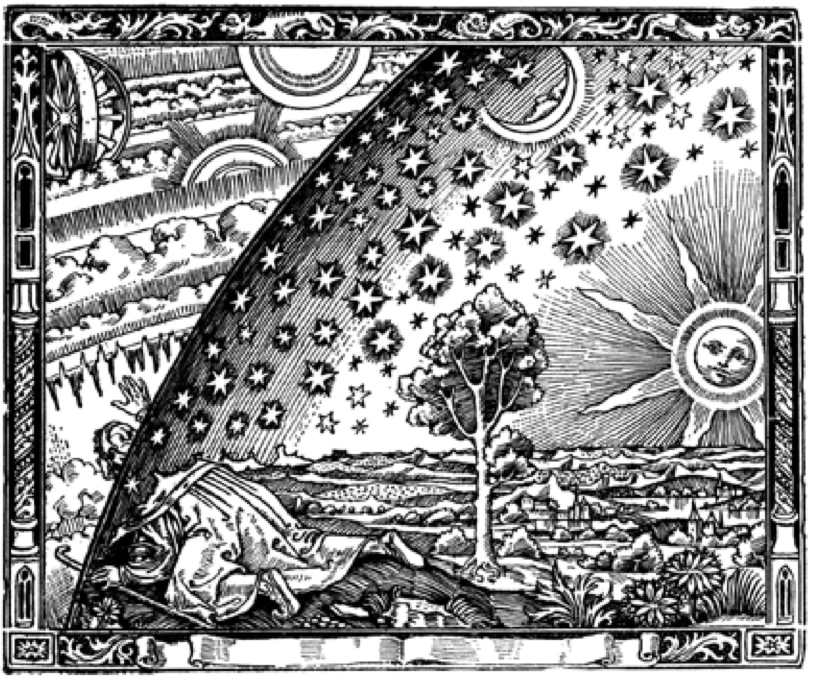
It is difficult to describe the limits of what is referred to in Polish as *nauka*. The word has multiple meanings, notably science (or even a discipline of science), research, education, and study, but it can also refer to the process of teaching or learning. I will therefore restrict myself here to the primary meaning of the word *nauka*, defined as "the study of things and phenomena and the resulting knowledge."

Yet even with this limitation, the Polish word *nauka* covers a broad array of meanings, and can be used to refer to numerous fields of study and disciplines, including theology and even sports science.

I am neither prepared nor qualified to discuss the limits of what is studied in all the fields that are called *nauka* in Polish. I can only comment relatively reasonably on those that are described in English or French using the term "science."



Der Himmelsgucker. The drawing comes from Camille Flammarion's *L'Atmosphère, météorologie populaire*, Paris 1888. Source: Wolfgang Bickel, "Das kanonische Bild – ein problematischer Gegenstand," *Praxis Geschichte*, No. 11 (1998), Issue 5, p. 57, cited after Wikimedia Commons

The object of study and its boundaries

The limits of scientific research may result from the presence of the boundaries of the objects under study. One example is descriptive geography, which I consider to be a science that is close to being complete. Clearly, there are still a great number of objects to be studied on our planet. Although we have studied, with a high degree of accuracy, almost the entire land surface of the Earth, the oceans remain poorly explored. I can imagine, though, that in the future, perhaps at a time not very far in the future, the full body of knowledge of descriptive geography will be converted into a collection of information stored on hard drives or the pages of hefty volumes.

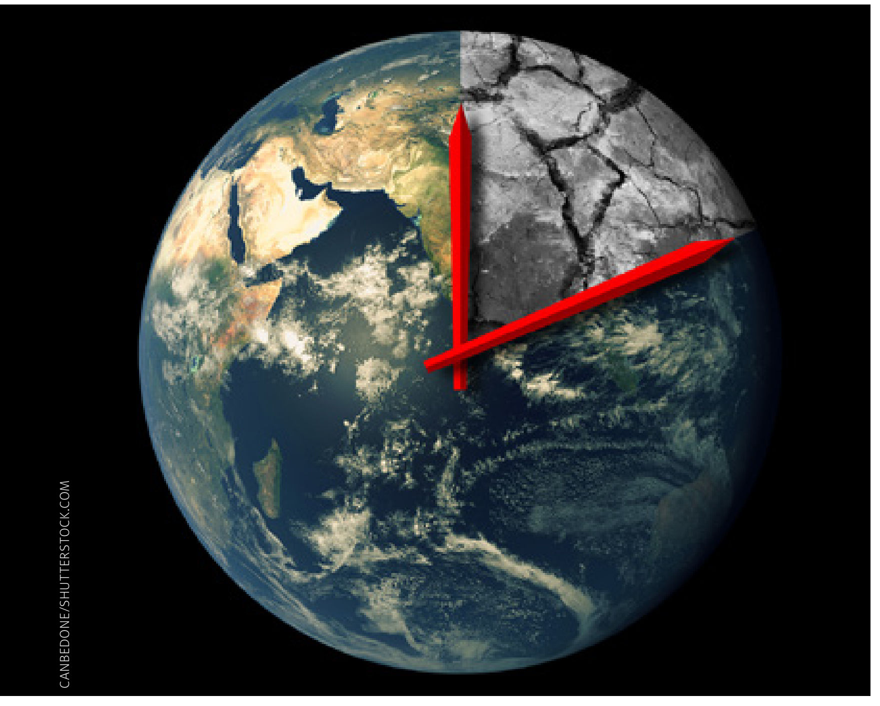
Another example I can think of comes from chemistry. For many centuries, alchemists argued that all things around us were made up of only four basic elements: water, earth, air, and fire. However, they were convinced that the number of possible combinations of those four elements was infinitely great. In the times of alchemists, even metals were believed to be mixtures of these elements.

As chemistry evolved, the alchemists were proved wrong. Today, we know that there are more than four basic elements, although their number is indeed finite. They are organized in the periodic table of elements, discovered by Dmitri Mendeleev. An element's numerical place in the table is determined by its atomic number, which is the number of protons found in the nucleus of its atoms. Until a few decades ago, the last element in the periodic table – and the heaviest known element – was uranium, with an atomic number of 92.

In the 1940s, physicists began to create heavier elements in ion-collision experiments at ever-higher energies. The first elements so produced were neptunium and plutonium, which have 93 and 94 protons in their nuclei, respectively. These elements are unstable and undergo rapid radioactive decay, so they are not found in nature in stable forms.

Today, we already know of 118 elements. The heaviest ones are highly unstable. The element with an atomic number of 118, called oganesson, persists for a mere fraction of a millisecond. We have grounds to believe that we have almost reached the limit of the number of elements. However, there are suspicions that there may still be an "island of stability" – a few relatively stable elements with atomic numbers somewhere around 124. No heavier elements could exist because the nuclear force cannot hold together too many protons and neutrons. To sum up, heavy elements can be created in ion collisions in physics laboratories or during violent astrophysical processes, but they disappear after a very small fraction of a second, turning into lighter and stabler elements.

The number of chemical elements is finite, but it may be slightly higher than 118. Likewise, we believe that the number of chemical compounds (substances composed of atoms of two or more elements held together by chemical bonds), is very large, but it is likewise finite. We do not know if we will ever know all possible chemical compounds, but we do know that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their number cannot be infinite. This fact delineates a certain limit of scientific research, although this limit is very distant. We may even never reach it.

Is there a limit to our study of the universe?

Aristotle would have answered this question affirmatively because he was certain that the universe was spherical and small, and there was nothing beyond it, "neither void, nor time."

That view persisted for many centuries, despite the fact that the space extending beyond the boundaries of the universe later became "populated" with deities, angels, saints, and the machinery that set the world in motion. In the early 17th century, Johannes Kepler estimated that the thickness of the sphere of fixed stars that enclosed the universe was only 15 kilometers.

Today, we look at the universe differently. First, let's reiterate certain facts.

We receive information about the world around us almost exclusively through electromagnetic waves. We perceive a certain range of wavelengths within the electromagnetic spectrum as visible light. We can detect the remaining portion of the electromagnetic spectrum using instruments, and we call it invisible light. Importantly, light travels at a great speed, namely approximately 300,000 kilometers per second. Such speed is difficult to imagine, but it is not infinitely great. To travel the length of the page the readers of this article are now looking at, light needs one nanosecond, or one billionth of a second. But to travel from the Earth to the Moon and back, light needs three seconds. We could observe this on the occasion of the Apollo missions in 1969–1972. The recent landing of the Perseverance rover on Mars had to take place automatically because the distance between Mars and Earth at the time was as much as 11 light-minutes.

Everyday measures for distances are not very well-suited to express huge astronomical distances, which is why scientists use special units for measuring them. The first of these is called a light-year. It's equivalent to the distance that light travels in one year in a vacuum at an enormous speed of about 300,000 kilometers per second, which means nearly 10 trillion kilometers (10^{13} km).

In order to express distance in the universe, we use an even larger unit called a megaparsec (Mpc), which is equal to 3.26 million light years.

We know that atoms emit and absorb light of certain wavelengths, specific to each element. These are called spectral lines. We can observe them in the light of celestial objects and use them to learn about which elements are present there.

About 100 years ago, people began to study the spectra of galaxies and found that the lines in their spectra were mostly shifted towards the red (or "redshifted") compared with the laboratory measurements on Earth. An American astronomer named Edwin Hubble determined the distances of dozens of galaxies with greater accuracy. In 1929, he announced that the shifting of the spectral lines of galaxies towards the red was directly proportional to their distance.

A simple explanation swiftly presented itself: the redshift was caused by the Doppler effect, which is related to the observer's movement relative to the source. We can routinely observe it in the case of sound waves: when an ambulance speeds past us, the frequency of the sound of its siren changes rapidly, and the pitch comes down. The change in the frequency of the wave is proportional to its speed. In the Doppler effect for light waves, as the distance between the observer and the source of the light increases, so do does the wavelength, which translates into a shift of the spectral lines towards the red.

Hubble adopted that interpretation and announced that galaxies were moving away from us at a velocity (v) proportional to their distance (r). This relationship can be expressed using the simple equation $v = H r$, where H is called the Hubble constant. The unit of the Hubble constant is inverse time, and it is quoted in a somewhat complicated way, in km/s per megaparsec. According to current measurements, the Hubble constant is about 70 (km/s)/Mpc. This means that as the distance of the galaxy increases by one megaparsec, the velocity at which it moves away grows by around 70 km/s.

Observational data obtained later has forced us to modify the initial interpretation of this phenomenon as being the result of the movement of galaxies through space. Rather, now we know that it is space itself that is expanding.

The inverse of the Hubble constant is about 13.8 billion years. It is known as the Hubble Time, the characteristic time of the expansion of the universe. If galaxies are now moving away from us, they must have been located closer to us and to one another in the past. About 13.8 billion years ago, all the matter in the visible universe was extremely densely "packed." Then, the "Big Bang" occurred, which initiated the expansion of the universe.

Importantly, that Big Bang was different from the explosions we know from Earth. An explosion spreads out from a center, covering more and more space. By contrast, the Big Bang occurred throughout space all at once as each particle of matter began to move away from all other particles. We assume that at that moment, space, which was filled with dense and hot matter, may have been infinite. After all, if we shrink space that is infinite by any factor, it will remain infinite.

Space expands in the same way in all directions. Regardless of the direction, the same relationship is found between the distance of galaxies and the velocity at which they move away. We might think that we occupy a unique place in the universe, but this is not the case.

To illustrate the expansion of the universe, we often use the example of a rubber balloon with dots painted on its surface. When we inflate the balloon, its surface expands, and the greater the distance between individual dots, the faster they move from one another. No single dot on the balloon could be considered to be the starting point for the expansion.

However, this analogy is flawed because as the rubber surface of the balloon expands, the dots also grow in size. But this is not the case in the universe: only the empty space between galaxies expands, whereas their sizes remain unchanged. This is because galaxies are star systems bound together by gravity, and the factor causing the expansion of space (which some call "dark energy") is much weaker than the attractive force of gravity.

But we can use a somewhat better analogy, namely that of raisin bread. As the dough rises during baking, the raisins move further and further away from one another, so an observer located on any raisin might conclude that all other raisins are moving away from him. If the dough rose in the same way in all directions, our hypothetical observer would find a linear

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A photograph showing hundreds of distant galaxies captured by the Hubble Space Telescope. If there are any intelligent beings living in a distant galaxy, they also see their universe as a sphere with a radius of about 46 billion light-years.

relationship between the velocity at which the raisins moved away and the distance between him and the remaining raisins, in the same way as this was done for galaxies. However, we would have to imagine that the dough is not in any enclosed container, but it can expand arbitrarily in all directions.

Since the Big Bang occurred some 13.8 billion years ago, the visible universe has been expanding. As galaxies grow farther apart from one another, light needs more time to travel between them. The most distant visible objects in the universe that we can see today, if we look in any direction, are about 46 billion light-years away. This is the boundary of our universe. We have no way of knowing what lies beyond it.

Somewhere far away in the universe

If there are any intelligent beings living in a galaxy located several billion light-years away from us, they also see their universe as a sphere with a radius of about 46 billion light-years. It only partially overlaps with the universe as we see it.

Eventually, space will expand so much that light will not be able to travel the ever-widening distance between galaxies. Such simulations of the evolution of the universe are made more difficult by numerous unknowns. Not so long ago, the Hubble constant, a measure of the current rate of the expansion of the universe, was considered to be unchanged in time. But recent observations suggest that the universe is now expanding faster. We do not know what the situation was like in the past.

The limits of the human mind

So far, we have discussed some of the limits of scientific research that arise from the very nature of the objects being studied. But what can we say about the limits of science that result from the nature of the human mind? It is said that we use only a small percentage of our brain cells. Arguably, we might be able to increase this share to process the growing amount of increasingly complex information. We could also design more and more powerful computers. We don't know the limits of artificial intelligence, but we do know that such limits must exist, because the limit of the speed of processors is determined by the speed of light, by which signals are exchanged between individual components.

The end of our civilization – the end of science

Needless to say, the end of science would be caused by the destruction of our civilization. Until recently, we only considered very rare disasters of astronomical origin, sketching out idyllic pictures of the development of mankind, like the one described by Erazm Majewski in his book *Koniec świata. Przegląd wypadków, jakie mogą sprowadzić zagładę Ziemi* [The End of the World: An Overview of Disasters That Could Destroy the Earth] (Warsaw 1887):

> *It is a certainty that mankind will reach such a state of perfection that we cannot even comprehend today. (...) The social system will be perfected. Education will become universal. (...) Most likely, there will be no nations, the most shameful international conflicts will disappear, and the Earth will become the common homeland of one people whose name will be "mankind." Even the streams of blood, once shed abundantly in fratricidal battles, will fade from memory.*

Today, we look at these issues differently. Prof. Martin Rees, a British scholar and the Astronomer Royal, wrote a moving book that was published in New York in 2003 as *Our Final Hour: A Scientist's Warning*. In the book, he discussed the phenomena that threatened the life of humans on Earth. He expressed the opinion that in the coming decades cataclysms caused by climate change would pose a greater danger to us than astronomical events. The 21st century is also marked by rapid depletion of fossil fuels and other natural resources, a rise in the number of natural disasters, as well as fresh water and food shortages.

Unfortunately, the species *Homo sapiens* tends to resolve problems by resorting to aggression. This does not necessarily mean an open war. Terrorist acts – be they "conventional," nuclear, biological, or cyberattacks – will be enough.

Religions could do a great deal to help humans come to their senses, but they are mostly busy trying to convince people how good things will be for them after they die. Consequently, Prof. Reed's final conclusion is rather pessimistic:

> *I think that the odds are no better than fifty-fifty that our present civilisation on Earth will survive to the end of the present century.*

Consequently, we may soon witness a cataclysm that will destroy our civilisation. In the eyes of simple people, the blame for this could be pinned on scientists. This could also mean the end of science.

W 1975, Ursula Le Guin published a collection of short stories entitled *The Wind's Twelve Quarters*. One of those stories, "The Masters," is truly shocking. It is set in a post-apocalyptic world in which science is forbidden and punishable by death. Is that what the end of science will look like? Perhaps we should remain optimistic nonetheless. After all, we reportedly have a fifty-fifty chance of survival. ■


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