How does conflict create new knowledge

It seems preposterous to us today that people once thought that the Earth was flat. Who could have possibly thought of our planet as a giant disk with the stars and heavens above, and boulders, tree roots, and other things below? But this was the dominant view of Earth in much of the world before the 2nd century [BCE](https://www.visionlearning.com/en/glossary/view/BCE/pop), though the details differed from culture to culture. And it was not explorers who sailed around the world that finally laid the idea to rest, but an accumulation of [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) long before this.

**Figure 1:** Representation of Eratosthenes' studies demonstrating the curvature of Earth and the geometry used to calculate the circumference of the planet. (Click to see additional information in larger version)

Greek philosophers referred to a spherical Earth as early as the 6th century [BCE](https://www.visionlearning.com/en/glossary/view/BCE/pop). They observed that the moon appeared to be a sphere and therefore inferred that Earth might also be spherical. Two hundred years later, in the 4th century BCE, the Greek philosopher [Aristotle](https://www.visionlearning.com/en/glossary/view/Aristotle/pop) observed that the shadow of the Earth on the Moon during a [lunar eclipse](https://www.visionlearning.com/en/glossary/view/lunar%2Beclipse/pop) is always curved, thus providing some of the first [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) that Earth is spherical. In the 3rd century BCE, the mathematician [Eratosthenes](https://www.visionlearning.com/en/glossary/view/Eratosthenes/pop) observed that at noon on the summer solstice in the ancient Egyptian city of Syene, the sun was directly overhead as objects did not cast a shadow. Eratosthenes was from Alexandria, Egypt, some 500 miles to the north, and he knew that a tall tower cast a shadow in that city at the same time on the summer solstice. Using these [observations](https://www.visionlearning.com/en/glossary/view/observation/pop) and measurements of shadow length and distance, he inferred that the [surface](https://www.visionlearning.com/en/glossary/view/surface/pop) of the Earth is curved and he calculated a remarkably accurate estimate of the circumference of the planet (Figure 1). Some years later, the Greek geographer Strabo added to this evidence when he observed that sailors saw distant objects move downward on the horizon and disappear as they sailed away from them. He proposed that this was because Earth was curved and those sailors were not simply moving further away from the objects but also curving around the planet as they sailed.

**Figure 2:** *Earthrise* taken on December 24, 1968, from the Apollo 8 mission.image © NASA

Aristotle, [Eratosthenes](https://www.visionlearning.com/en/glossary/view/Eratosthenes/pop), and Strabo didn't call themselves scientists, yet they were using the [process](https://www.visionlearning.com/en/glossary/view/process/pop) of science by making [observations](https://www.visionlearning.com/en/glossary/view/observation/pop) and providing explanations for those observations. Thus, we knew that Earth was a sphere long before [Ferdinand Magellan](https://www.visionlearning.com/en/glossary/view/Magellan%2C%2BFerdinand/pop)'s men sailed all the way around it in 1522 or before Apollo 8 astronauts sent back pictures of Earth from space in 1968 (Figure 2), documenting its spherical shape. In fact, those astronauts had to be absolutely confident that the Earth was a rotating sphere, orbiting the Sun, or they would never have been able to get into orbit. It is the nature of science and scientific knowledge that gave them that confidence, and understanding the difference between scientific knowledge and other types of knowledge is critical to understanding science itself.

**What is science?**

Science consists of two things: a body of knowledge and the [process](https://www.visionlearning.com/en/glossary/view/process/pop) by which that knowledge is produced. This second component of science provides us with a way of thinking and knowing about the world. Commonly, we only see the "body of knowledge" component of science. We are presented with scientific concepts in statement form – Earth is round, [electrons](https://www.visionlearning.com/en/glossary/view/electron/pop) are negatively charged, our genetic code is contained in our [DNA](https://www.visionlearning.com/en/glossary/view/DNA/pop), the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) is 13.7 billion years old – with little background about the process that led to that knowledge and why we can trust it. But there are a number of things that distinguish the scientific process and give us confidence in the knowledge produced through it.

So then, what is the scientific process? The scientific [process](https://www.visionlearning.com/en/glossary/view/process/pop) is a way of building knowledge and making predictions about the world in such a way that they are testable. The question of whether Earth is flat or round could be put to the test, it could be studied through multiple lines of [research](https://www.visionlearning.com/en/glossary/view/research/pop), and the [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) evaluated to determine whether it supported a round or flat planet. Different scientific disciplines typically use different [methods](https://www.visionlearning.com/en/glossary/view/method/pop) and approaches to investigate the natural world, but testing lies at the core of scientific inquiry for all scientists.

As scientists analyze and interpret their [data](https://www.visionlearning.com/en/glossary/view/data/pop) (see our [Data Analysis and Interpretation](http://www.visionlearning.com/library/module_viewer.php?mid=154&l=) module), they generate [hypotheses](https://www.visionlearning.com/en/glossary/view/hypothesis/pop), [theories](https://www.visionlearning.com/en/glossary/view/theory/pop), or [laws](https://www.visionlearning.com/en/glossary/view/law/pop) (see our [Theories, Hypotheses, and Laws](http://www.visionlearning.com/library/module_viewer.php?mid=177&l=) module), which help explain their results and place them in context of the larger body of scientific knowledge. These different kinds of explanations are tested by scientists through additional [experiments](https://www.visionlearning.com/en/glossary/view/experiment/pop), [observations](https://www.visionlearning.com/en/glossary/view/observation/pop), modeling, and theoretical studies. Thus, the body of scientific knowledge builds on previous ideas and is constantly growing. It is deliberately shared with colleagues through the [process](https://www.visionlearning.com/en/glossary/view/process/pop) of [peer review](https://www.visionlearning.com/en/glossary/view/peer%2Breview/pop) (see our [Peer Review](http://www.visionlearning.com/library/module_viewer.php?mid=159&l=) module), where scientists comment on each other's work, and then through publication in the scientific literature (see our [Utilizing the Scientific Literature](http://www.visionlearning.com/library/module_viewer.php?mid=173&l=) module), where it can be evaluated and integrated into the body of scientific knowledge by the larger community. And this is not the end: One of the hallmarks of scientific knowledge is that it is subject to change, as new data are collected and reinterpretations of existing data are made. Major theories, which are supported by multiple lines of [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop), are rarely completely changed, but new data and tested explanations add nuance and detail.

A scientific way of thinking is something that anyone can use, at any time, whether or not they are in the [process](https://www.visionlearning.com/en/glossary/view/process/pop) of developing new knowledge and explanations. Thinking scientifically involves asking questions that can be answered analytically by collecting [data](https://www.visionlearning.com/en/glossary/view/data/pop) or creating a [model](https://www.visionlearning.com/en/glossary/view/model/pop) and then testing one's ideas. A scientific way of thinking inherently includes creativity in approaching explanations while staying within the confines of the data. Thinking scientifically does not mean rejecting your culture and background, but recognizing the role that they play in your way of thinking. While testable explanations are a critical component of thinking scientifically, there are other valid ways of thinking about the world around us that do not always yield testable explanations. These different ways of thinking are complementary – not in competition – as they address different aspects of the human experience.

It's easy to be confident in the scientific [process](https://www.visionlearning.com/en/glossary/view/process/pop) and our knowledge when we can provide irrefutable [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop), as we were able to do by orbiting around the Earth in a spaceship and taking pictures of an obviously round planet. But most scientific investigations do not lead to results that are so easily supported, and yet we still rely on and trust the knowledge produced through the process of science. Why do we trust it? Because it works. Science has a long history of creating knowledge that is useful and that gives us more insight into our surroundings. Take one of the statements above: The [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) is 13.7 billion years old. Why should we have confidence in this statement?

Comprehension Checkpoint

**The scientific process is a way of building knowledge and making predictions that**

Top of Form

* can be tested.
* are accepted as scientific law.

Bottom of Form

**The age of the universe**

How old is the universe? How can we possibly know the age of something that was created not simply before human history, but before our planet came into being? This is a difficult question to address scientifically, so much so that through the early 20th century many scientists assumed that the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) was infinite and eternal, existing for all of time.

**Machines and entropy**

The first indication that the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) may not have existed for all of time came from an unlikely source: the study of engines. In the 1820s, [Sadi Carnot](https://www.visionlearning.com/en/glossary/view/Carnot%2C%2BSadi/pop%22%20%5Co%20%22) was a young officer on leave from the French military. While taking classes at various institutions in Paris, he became interested in industrial problems, and was surprised to see that no scientific studies had been undertaken on the steam engine, a relatively new invention at the time and a poorly understood one. Carnot believed that engines could be better understood – a characteristic common to scientists is that they work to better understand things – and so he studied the transfer of [energy](https://www.visionlearning.com/en/glossary/view/energy/pop) in engines. He recognized that no engine could be 100% efficient because some energy is always lost from the [system](https://www.visionlearning.com/en/glossary/view/system/pop) as [heat](https://www.visionlearning.com/en/glossary/view/heat/pop) (Figure 3). Carnot published his ideas in a book titled *Reflections on the Motive Power of Fire and on Machines Fitted to Develop that Power*, which presented a mathematical description of the amount of [work](https://www.visionlearning.com/en/glossary/view/work/pop) that could be generated by an engine, called the [Carnot cycle](https://www.visionlearning.com/en/glossary/view/Carnot%2BCycle/pop) (Carnot, 1824).

**Figure 3:** An infrared image of a running engine showing the temperature of various parts of the engine. Higher temperatures (red and yellow portions of the image) indicate greater heat loss. The loss of heat represents a loss of efficiency in the engine, and a contribution to the increasing entropy of the universe.image © Epogee, Ltd

Carnot's work didn't receive much attention during his lifetime, and he died of cholera in 1832, when he was only 36 years old. But others began to realize the importance of his work and built upon it. One of those scientists was [Rudolf Clausius](https://www.visionlearning.com/en/glossary/view/Clausius%2C%2BRudolf/pop), a German physicist who showed that Carnot's [principle](https://www.visionlearning.com/en/glossary/view/principle/pop) was not limited to engines, but in fact applied to all [systems](https://www.visionlearning.com/en/glossary/view/system/pop) in which there was a transfer of [energy](https://www.visionlearning.com/en/glossary/view/energy/pop). Clausius' application of an explanation for one phenomenon to many others is also characteristic of science, which assumes that processes are universal.

In 1850, Clausius published a paper in which he developed the second [law](https://www.visionlearning.com/en/glossary/view/law/pop) of thermodynamics, which states that [energy](https://www.visionlearning.com/en/glossary/view/energy/pop) always flows from a high energy state (for example, a [system](https://www.visionlearning.com/en/glossary/view/system/pop) that is hot) to a low energy state (one that is cold) (Clausius, 1850). In later work, Clausius coined the term [entropy](https://www.visionlearning.com/en/glossary/view/entropy/pop) to describe the energy lost from a system when it is transferred, and as an acknowledgement of the pioneering work of [Sadi Carnot](https://www.visionlearning.com/en/glossary/view/Carnot%2C%2BSadi/pop%22%20%5Co%20%22) in providing the foundation for his discoveries, Clausius used the symbol S to refer to the entropy of a system.

But how do engines and [entropy](https://www.visionlearning.com/en/glossary/view/entropy/pop) relate to the age of the universe? In 1865, Clausius published another paper that restated the Second [Law](https://www.visionlearning.com/en/glossary/view/law/pop) of Thermodynamics as "the entropy of the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) tends to a maximum." If the universe was infinite and existed for all time, the [Second Law of Thermodynamics](https://www.visionlearning.com/en/glossary/view/Second%2BLaw%2Bof%2BThermodynamics/pop) says that all of the [energy](https://www.visionlearning.com/en/glossary/view/energy/pop) within the universe would have been lost to entropy by now. In other words, the stars themselves would have burned out long ago, dissipating their [heat](https://www.visionlearning.com/en/glossary/view/heat/pop) into surrounding space. The fact that there are still active stars must mean that the universe has existed for a finite amount of time, and was created at some specific point in time. Perhaps the age of that point in time could be determined?

Comprehension Checkpoint

**Science assumes that**

Top of Form

* natural processes are universal.
* each process is particular to the individual system being observed.

Bottom of Form

**Redshift and the Doppler effect**

At about the same time, an Austrian physicist by the name of [Christian Doppler](https://www.visionlearning.com/en/glossary/view/Doppler%2C%2BChristian/pop) was studying astronomy and mathematics. Doppler knew that [light](https://www.visionlearning.com/en/glossary/view/light/pop) behaved like a wave, and so began to think about how the movement of stars might affect the light emitted from those stars. In a paper published in 1842, Doppler proposed that the observed [frequency](https://www.visionlearning.com/en/glossary/view/frequency/pop) of a wave would depend on the relative speed of the wave's source in relation to the observer, a phenomenon he called a "frequency shift" (Doppler, 1842). He made an analogy to a ship at sail on the ocean, describing how the ship would encounter [waves](https://www.visionlearning.com/en/glossary/view/waves/pop) on the [surface](https://www.visionlearning.com/en/glossary/view/surface/pop) of the water at a faster rate (and thus higher frequency) if it were sailing into the [waves](https://www.visionlearning.com/en/glossary/view/waves/pop) than if it were traveling in the same direction as the waves.

You might be familiar with the [frequency](https://www.visionlearning.com/en/glossary/view/frequency/pop) shift, which we now call the [Doppler Effect](https://www.visionlearning.com/en/glossary/view/Doppler%2Beffect/pop) in his honor, if you have ever listened to the sound of traffic while standing on the side of the road. The familiar high-to-low pitch change is an example of the effect – the actual frequency of the [waves](https://www.visionlearning.com/en/glossary/view/waves/pop) emitted is not changing, but the speed of the passing vehicle affects how quickly those [waves](https://www.visionlearning.com/en/glossary/view/waves/pop) reach you. Doppler proposed that we would see the same effect on any stars that were moving: Their color would shift towards the red end of the [spectrum](https://www.visionlearning.com/en/glossary/view/spectrum/pop) if they were moving away from Earth (called a *redshift*) and towards the blue end of the spectrum if they were moving closer (called a *blueshift*) (see Figure 4). He expected to be able to see this shift in [binary stars](https://www.visionlearning.com/en/glossary/view/binary%2Bstars/pop), or pairs of stars that orbit around each other. Eventually, Doppler's 1842 paper, entitled "On the coloured [light](https://www.visionlearning.com/en/glossary/view/light/pop) of the double stars and certain other stars of the heavens," would change the very way we look at the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop). However, at the time, telescopes were not sensitive enough to confirm the shift he proposed.

**Figure 4:** A representation of how the perceived spectrum of light emitted from a galaxy is affected by its motion (Click to see additional information in larger version).

Doppler's ideas became part of the scientific literature and by that means became known to other scientists. By the early 1900s, technology finally caught up with Doppler and more powerful telescopes could be used to test his ideas. In September of 1901, an American named Vesto Slipher had just completed his undergraduate degree in mechanics and astronomy at Indiana University. He got a job as a temporary assistant at the Lowell Observatory in Flagstaff, Arizona, while continuing his graduate work at Indiana. Shortly after his arrival, the observatory obtained a three-prism [spectrograph](https://www.visionlearning.com/en/glossary/view/spectrograph/pop), and Slipher's job was to mount it to the 24-inch telescope at the observatory and learn to use it to study the rotation of the planets in the solar [system](https://www.visionlearning.com/en/glossary/view/system/pop). After a few months of problems and trouble-shooting, Slipher was able to take [spectrograms](https://www.visionlearning.com/en/glossary/view/spectrogram/pop) of Mars, Jupiter, and Saturn. But Slipher's personal [research](https://www.visionlearning.com/en/glossary/view/research/pop) interests were much farther away than the planets of the solar system. Like Doppler, he was interested in studying the spectra of [binary stars](https://www.visionlearning.com/en/glossary/view/binary%2Bstars/pop), and he began to do so in his spare time at the observatory.

Over the next decade, Slipher completed a Master's degree and a PhD at Indiana University, while continuing his work at Lowell Observatory measuring the spectra and Doppler shift of stars. In particular, Slipher focused his attention on stars within spiral [nebulae](https://www.visionlearning.com/en/glossary/view/nebulae/pop) (Figure 5), expecting to find that the shift seen in the spectra of the stars would indicate that the galaxies those stars belonged to were rotating. Indeed, he is credited with determining that galaxies rotate, and was able to determine the [velocities](https://www.visionlearning.com/en/glossary/view/velocity/pop) at which they rotate. But in 1914, having studied 15 different nebulae, he announced a curious discovery at a meeting of the American Astronomical Society in August:

In the great majority of cases the nebulae are receding; the largest velocities are all positive...The striking preponderance of the positive sign indicates a general fleeing from us or the Milky Way.

Slipher had found that most galaxies showed a [redshift](https://www.visionlearning.com/en/glossary/view/redshift/pop) in their [spectrum](https://www.visionlearning.com/en/glossary/view/spectrum/pop), indicating that they were all moving away from us in space, or receding (Slipher, 1915). By measuring the magnitude of the redshift, he was able to determine the recessional [velocity](https://www.visionlearning.com/en/glossary/view/velocity/pop) or the speed at which objects were "fleeing." Slipher had made an [interpretation](https://www.visionlearning.com/en/glossary/view/interpretation/pop) from his [observations](https://www.visionlearning.com/en/glossary/view/observation/pop) that put a new perspective on the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop), and in response, he received a standing ovation for his presentation.

**Figure 5:** The Andromeda galaxy, one of the spiral nebulae studied by Vesto Slipher, as seen in infrared light by NASA's Wide-field Infrared Survey Explorer.image © NASA

Slipher continued his work with [redshift](https://www.visionlearning.com/en/glossary/view/redshift/pop) and galaxies and published another paper in 1917, having now examined 25 [nebulae](https://www.visionlearning.com/en/glossary/view/nebulae/pop) and seen a redshift in 21 of them. Georges Lemaître, a Belgian physicist and astronomer, built on Slipher's work while completing his PhD at the Massachusetts Institute of Technology. He extended Slipher's measurements to the entire [universe](https://www.visionlearning.com/en/glossary/view/universe/pop), and calculated mathematically that the universe must be expanding in order to explain Slipher's [observation](https://www.visionlearning.com/en/glossary/view/observation/pop). He published his ideas in a 1927 paper called "A homogeneous Universe of [constant](https://www.visionlearning.com/en/glossary/view/constant/pop) [mass](https://www.visionlearning.com/en/glossary/view/mass/pop) and growing radius accounting for the radial [velocity](https://www.visionlearning.com/en/glossary/view/velocity/pop) of extragalactic nebulae" (Lemaître, 1927), but his paper met with widespread criticism from the scientific community. The English astronomer Fred Hoyle ridiculed the work, and coined the term "Big Bang" [theory](https://www.visionlearning.com/en/glossary/view/theory/pop) as a disparaging nickname for Lemaître's idea. And none other than [Albert Einstein](https://www.visionlearning.com/en/glossary/view/Einstein%2C%2BAlbert/pop) criticized Lemaître, writing to him "Your math is correct, but your physics is abominable" (Deprit, 1984).

Einstein's criticism had a personal and cultural component, two things we often overlook in terms of their influence on science. Several years earlier, Einstein had published his general [theory](https://www.visionlearning.com/en/glossary/view/theory/pop) of [relativity](https://www.visionlearning.com/en/glossary/view/relativity/pop) (Einstein, 1916). In formulating the theory, Einstein had encountered one significant problem: General relativity predicted that the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) had to be either contracting or expanding – it did not allow for a static universe. But a contracting or expanding universe could not be eternal, while a static, non-moving universe could, and the prevailing cultural belief at the time was that the universe was eternal. Einstein was strongly influenced by his cultural surroundings. As a result, he invented a "fudge factor," which he called the cosmological [constant](https://www.visionlearning.com/en/glossary/view/constant/pop), that would allow the theory of general relativity to be consistent with a static universe. But science is not a democracy or plutocracy; it is neither the most common or most popular conclusion that becomes accepted, but rather the conclusion that stands up to the test of [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) over time. Einstein's cosmological constant was being challenged by new evidence.

Comprehension Checkpoint

**Scientists are not influenced by their personal experiences, their beliefs, or the culture of which they are a part.**

Top of Form

* true
* false

Bottom of Form

**The expanding universe**

In 1929, an American astronomer working at the Mt. Wilson Observatory in southern California made an important contribution to the discussion of the nature of the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop). [Edwin Hubble](https://www.visionlearning.com/en/glossary/view/Hubble%2C%2BEdwin%2BPowell/pop) had been at Mt. Wilson for 10 years, measuring the distances to galaxies, among other things. In the 1920s, he was working with Milton Humason, a high school dropout and assistant at the observatory. Hubble and Humason plotted the distances they had calculated for 46 different galaxies against Slipher's recession [velocity](https://www.visionlearning.com/en/glossary/view/velocity/pop) and found a linear relationship (see Figure 6) (Hubble, 1929).

**Figure 6:** The original Hubble diagram. The relative velocity of galaxies (in km/sec) is plotted against distance to that galaxy (in parsecs; a parsec is 3.26 light years). The slope of the line drawn through the points gives the rate of expansion of the universe (the Hubble Constant). (Originally Figure 1, from "A Relation Between Distance and Radial Velocity Among Extra-Galactic Nebulae," Proceedings of the National Academy of Sciences, Volume 15, Issue 3, 1929: p. 172. © Huntington Library, San Marino, CA.)image © The Huntington Library

In other words, their graph showed that more distant galaxies were receding faster than closer ones, confirming the idea that the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) was indeed expanding. This relationship, now referred to as Hubble's [Law](https://www.visionlearning.com/en/glossary/view/law/pop), allowed them to calculate the rate of expansion as a function of distance from the slope of the line in the graph. This rate term is now referred to as the Hubble [constant](https://www.visionlearning.com/en/glossary/view/constant/pop). Hubble's initial [value](https://www.visionlearning.com/en/glossary/view/value/pop) for the expansion rate was 500 km/sec/Megaparsec, or about 160 km/sec per million-light-years.

Knowing the rate at which the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) is expanding, one can calculate the age of the universe by in essence "tracing back" the most distant objects in the universe to their point of origin. Using his initial [value](https://www.visionlearning.com/en/glossary/view/value/pop) for the expansion rate and the measured distance of the galaxies, Hubble and Humason calculated the age of the universe to be approximately 2 billion years. Unfortunately, the calculation was inconsistent with lines of [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) from other investigations. By the time Hubble made his discovery, geologists had used radioactive dating techniques to calculate the age of Earth at about 3 billion years (Rutherford, 1929) – or older than the universe itself! Hubble had followed the [process](https://www.visionlearning.com/en/glossary/view/process/pop) of science, so what was the problem?

Even [laws](https://www.visionlearning.com/en/glossary/view/law/pop) and [constants](https://www.visionlearning.com/en/glossary/view/constant/pop) are subject to revision in science. It soon became clear that there was a problem in the way that Hubble had calculated his constant. In the 1940s, a German astronomer named Walter Baade took advantage of the blackouts that were ordered in response to potential attacks during World War II and used the Mt. Wilson Observatory in Arizona to look at several objects that Hubble had interpreted as single stars. With darker surrounding skies, Baade realized that these objects were, in fact, groups of stars, and each was fainter, and thus more distant, than Hubble had calculated. Baade doubled the distance to these objects, and in turn halved the [Hubble constant](https://www.visionlearning.com/en/glossary/view/Hubble%2Bconstant/pop) and doubled the age of the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop). In 1953, the American astronomer Allan Sandage, who had studied under Baade, looked in more detail at the brightness of stars and how that varied with distance. Sandage further revised the constant, and his estimate of 75 km/sec/Megaparsec is close to our modern day estimate of the Hubble constant of 72 km/sec/Megaparsec, which places the age of the universe at 12 to 14 billion years old.

The new estimates developed by Baade and Sandage did not negate what Hubble had done (it is still called the Hubble [constant](https://www.visionlearning.com/en/glossary/view/constant/pop), after all), but they revised it based on new knowledge. The lasting knowledge of science is rarely the work of an individual, as building on the work of others is a critical component of the [process](https://www.visionlearning.com/en/glossary/view/process/pop) of science. Hubble's findings would have been limited to some interesting [data](https://www.visionlearning.com/en/glossary/view/data/pop) on the distance to various stars had it not also built on, and incorporated, the work of Slipher. Similarly, Baade and Sandage's contribution were no less significant because they "simply" refined Hubble's earlier work.

Since the 1950s, other means of calculating the age of the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) have been developed. For example, there are now [methods](https://www.visionlearning.com/en/glossary/view/method/pop) for dating the age of the stars, and the oldest stars date to approximately 13.2 billion years ago (Frebel et al., 2007). The Wilkinson Microwave Anisotropy Probe is collecting [data](https://www.visionlearning.com/en/glossary/view/data/pop) on [cosmic microwave background radiation](https://www.visionlearning.com/en/glossary/view/Cosmic%2BMicrowave%2BBackground%2BRadiation/pop) (Figure 7). Using these data in conjunction with Einstein's [theory](https://www.visionlearning.com/en/glossary/view/theory/pop) of general [relativity](https://www.visionlearning.com/en/glossary/view/relativity/pop), scientists have calculated the age of the universe at 13.7 ± 0.2 billion years old (Spergel et al., 2003). The convergence of multiple lines of [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) on a single explanation is what creates the [solid](https://www.visionlearning.com/en/glossary/view/solid/pop) foundation of scientific knowledge.

**Figure 7:** Visual representation of the cosmic microwave background radiation, and the temperature differences indicated by that radiation, as collected by the Wilkinson Microwave Anisotropy Probe.image © NASA/WMAP Science Team

Comprehension Checkpoint

**Major ideas in science are rarely the work of**

Top of Form

* individuals.
* multiple researchers.

Bottom of Form

**Why should we trust science?**

Why should we believe what scientists say about the age of the universe? We have no written [records](https://www.visionlearning.com/en/glossary/view/record/pop) of its creation, and no one has been able to "step outside" of the [system](https://www.visionlearning.com/en/glossary/view/system/pop), as astronauts did when they took pictures of Earth from space, to measure its age. Yet the nature of the scientific [process](https://www.visionlearning.com/en/glossary/view/process/pop) allows us to accurately state the age of the observable [universe](https://www.visionlearning.com/en/glossary/view/universe/pop). These predictions were developed by multiple researchers and tested through multiple [research](https://www.visionlearning.com/en/glossary/view/research/pop) [methods](https://www.visionlearning.com/en/glossary/view/method/pop). They have been presented to the scientific community through publications and public presentations. And they have been confirmed and verified by many different studies. New studies, or new research methods, may be developed that might possibly cause us to refine our estimate of the age of the universe upward or downward. This is how the process of science works; it is subject to change as more information and new technologies become available. But it is not tenuous – our age estimate may be refined, but the idea of an expanding universe is unlikely to be overturned. As [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) builds to support an idea, our confidence in that idea builds.

Upon seeing Hubble's work, even [Albert Einstein](https://www.visionlearning.com/en/glossary/view/Einstein%2C%2BAlbert/pop) changed his opinion of a static [universe](https://www.visionlearning.com/en/glossary/view/universe/pop) and called his insertion of the cosmological [constant](https://www.visionlearning.com/en/glossary/view/constant/pop) the "biggest blunder" of his professional career. Hubble's discovery actually confirmed Einstein's [theory](https://www.visionlearning.com/en/glossary/view/theory/pop) of general [relativity](https://www.visionlearning.com/en/glossary/view/relativity/pop), which predicts that the universe must be expanding or contracting. Einstein refused to accept this idea because of his cultural biases. His work had not predicted a static universe, but he assumed this must be the case given what he had grown up believing. When confronted with the [data](https://www.visionlearning.com/en/glossary/view/data/pop), he recognized that his earlier beliefs were flawed, and came to accept the findings of the science behind the idea. This is a hallmark of science: While an individual's beliefs may be biased by personal experience, the scientific enterprise works to collect data to allow for a more objective conclusion to be identified. Incorrect ideas may be upheld for some amount of time, but eventually the preponderance of [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) helps to lead us to correct these ideas. Once used as a term of disparagement, the "Big Bang" theory is now the leading explanation for the origin of the universe as we know it.

There are other questions we can ask about the origin of the [universe](https://www.visionlearning.com/en/glossary/view/universe/pop), not all of which can be answered by science. Scientists can answer when and how the universe began but cannot calculate the reason why it began, for example. That type of question must be explored through philosophy, religion, and other ways of thinking. The questions that scientists ask must be testable. Scientists have provided answers to testable questions that have helped us calculate the age of the universe, like how distant certain stars are and how fast they are receding from us. Whether or not we can get a definitive answer, we can be confident in the [process](https://www.visionlearning.com/en/glossary/view/process/pop) by which the explanations were developed, allowing us to rely on the knowledge that is produced through the process of science. Someday we may find [evidence](https://www.visionlearning.com/en/glossary/view/evidence/pop) to help us understand why the universe was created, but for the time being science will limit itself to the last 13.7 or so billion years of phenomena to investigate.

**Summary**

This module explores the nature of scientific knowledge by asking what science is. It emphasizes the importance of a scientific way of thinking and shows how observation and testing add to the body of scientific knowledge. Focusing on astronomy and physics, the module highlights the work of scientists through history who have contributed to our understanding of the age of the universe as a means of conveying the nature of scientific knowledge.

or many people, the purpose of pursuing organizational learning is to create new knowledge for competitive advantage. Although researchers and managers alike often assume that such knowledge ultimately proves its value in the form of innovative products and services, the link between learning, knowledge, and innovation can be elusive. There seem to be few cogent explanations of how to develop promising ideas and then put them into practice. Fortunately, management consultant Mark McElroy has courageously set off in search of this organizational Holy Grail in his book The New Knowledge Management: Complexity, Learning, and Sustainable Innovation (Butterworth-Heinemann, 2003).

**Two Generations of Knowledge Management**

While many of us were just grasping what the term knowledge management means, innovators at the Knowledge Management Consortium International (KMCI), the organization that McElroy heads and for which I serve as a board member, were already creating a new and improved iteration of the concept. Although some people may be tempted to dismiss this advance as being simply a case of old wine in new bottles, McElroy draws a bold line in the sand between these two distinctly different versions of knowledge management (KM). He explains how first-generation KM approaches are largely based on the notion that organizations are machines; from this perspective, knowledge and information are close cousins in that both are effectively managed through the use of technology. Practitioners of second-generation KM, on the other hand, adopt a more organic view; they regard information as a distant precursor to knowledge and view social processes as more critical than technology for creating new knowledge.

First-generation KM is based on the assumption that knowledge is a well-defined commodity that can be easily used by people throughout a company and that the main task of KM initiatives is to leverage the use of existing knowledge by sharing it freely throughout an organization. Technology becomes valued as an efficient means to accomplish this goal. Therefore, first-generation KM approaches typically focus on the use of technology to collect, analyze, and store data — especially best practices — that organizations can use to improve performance. For instance, a company’s sales force may use wireless systems to capture insights and lessons learned about customer buying patterns and competitor strategies. They then channel this information to someone within the organization who will organize it, conduct meta-data analyses to draw overarching conclusions, and place the results into a computer database. Such databases are then made available to employees through corporate intranets. Employees may access information such as lists of handy selling tips for approaching customers with certain profiles and strategies for increasing sales that have been developed and used successfully by other members of the sales force. Some of these database systems use “Yellow Pages” directories and expertise profiling to help practitioners connect with those colleagues who have demonstrated successes.

Although such tools are technologically impressive, they tend to focus on identifying isolated elements of knowledge, out of their natural context, and fail to address the fundamental process by which knowledge is created in individuals and groups. Second-generation KM seeks to address this shortcoming. The notion that sharing tips about how a colleague successfully achieved a sale presumes that others can effectively use a similar strategy without changing what they believe, how they think, or how they perceive selling situations. Such an approach reduces selling from an art that is developed over years of experience to a form of behavioral mimicry.

**The Knowledge Life Cycle**

Whether or not you subscribe to the increasingly popular view that first-generation KM has already proven to be ineffective, McElroy gives compelling reasons to consider switching to second-generation KM. He addresses how (1) organizational learning is linked to KM, (2) knowledge drives innovation, (3) complexity and systems thinking are related to KM, and (4) corporate policies can be an important lever for creating knowledge and innovation (see “10 Key Principles of Second-Generation Knowledge Management” on p. 8). For example, in first-generation KM schemes, such as those that focus on creating formal mechanisms for sharing best practices, knowledge is driven by what we might call “supply-side considerations.” That is, the mere availability of new knowledge is assumed to be sufficient reason to distribute it to employees throughout the organization — regardless of whether they are satisfied with the knowledge they are currently using or even have the capability to use this new material. According to McElroy, second-generation KM approaches are primarily demand-driven. A good example is what human resource professionals call “just-in-time” training (JITT). Through JITT, employees can access training when they believe they need it to solve problems that concern them, rather than attend management-mandated workshops that may or may not provide them with timely information.

In addition, according to the KMCI knowledge life-cycle model that McElroy presents, high-quality knowledge evolves over time through dialogue within communities of practitioners who are committed to understanding what works best. Technological fixes, such as the one described above, are not a substitute for nurturing the essential social processes that contribute to developing new knowledge — they are an adjunct. It is this idea that McElroy tries to impress upon advocates of first-generation KM, who portray computer-based fixes as a main feature of KM rather than as a tool for facilitating it. Because of this limited view of KM’s applicability, it is not surprising that many executives have become skeptical of the discipline’s promise for delivering sustainable competitive advantage.

**10 KEY PRINCIPLES OF SECOND-GENERATION KNOWLEDGE MANAGEMENT**

1. Learning and innovation is a social process, not an administrative one.
2. Organizational learning and innovation is triggered by the detection of problems.
3. Valuable organizational knowledge does not simply exist — people in organization create it.
4. The social pattern of organizational learning and innovation is largely self-organizing and has regularity to it.
5. KM is a management discipline that focuses on enhancing knowledge production and integration in organizations.
6. KM is not an application of IT — rather, KM sometimes uses IT to help it have an impact on the social dynamics of knowledge and processing.
7. KM interventions can only have direct impact on knowledge-processing outcomes, not business outcomes — the impact on business outcomes is indirect.
8. KM enhances an organization’s capacity to adapt by improving its ability to learn and innovate, and to detect and solve problems.
9. If it doesn’t address value, veracity, or context, it’s not knowledge management.
10. Business strategy is subordinate to KM strategy, not the reverse, because business strategy is itself a product of knowledge processing.

**Knowledge-Friendly Policies**

In its essence, The New Knowledge Management espouses the perspective that managers cannot directly manage many critical organizational processes, such as knowledge creation, but they can influence them by judiciously altering certain factors. Xerox’s Palo Alto Research Center (PARC) is one enterprise that has organized knowledge management processes around people’s natural behaviors. For example, because workers tend to congregate around coffee pots, the company has installed white boards and markers in those areas to assist people in capturing the knowledge that emerges through informal conversations. In addition, because studies at Xerox revealed that people also tend to engage in conversations in stairways, the company facilitated this process by widening those areas so coworkers can remain on the stairs and chat while others still have room to pass by.

Likewise, McElroy argues that corporate policies often unintentionally stifle knowledge creation by favoring efficiency, and that managers should scrutinize and modify processes to be “knowledge-friendly.” In the latter portion of the book, in his description of the Policy Synchronization Method (PSM), he alludes to some key policy levers for systematically redesigning organizations to facilitate knowledge processing and innovation. PSM helps managers do a baseline diagnostic assessment of the effectiveness of current knowledge-processing systems and then alter policies and processes to yield greater innovation in how knowledge is created.

The importance of this naturalistic view of husbanding organizational processes, as opposed to managing them, cannot be overstated. The simplistic industrial engineering notions of Fredrick W. Taylor and others once served the prevailing Newtonian/ Cartesian mental models of managers well, but that era is over. Today, managers are killing organizations by sacrificing innovation to the god of efficiency. We shouldn’t be surprised to learn that stagnant, ineffective processes are traceable to an organization’s failure to create new knowledge, or that the solution lies in finding innovative ways to harness people’s talents, or intellectual capital, rather than in installing new hardware and software. Historically, tools and technology have always worked best when used to augment people’s know-how and understanding. While technologies can often replace people in simple, routine situations, they can’t generate innovation in complex, dynamic environments — that’s where the real value of second-generation KM is most apparent.

Does McElroy find the ultimate answer for achieving high organizational performance? Probably not. But in this writer’s opinion, he convincingly points toward a direction where it may be found, when many other so called knowledge management gurus remain bewitched by the lure of first-generation KM solutions. Second-generation KM — and McElroy’s book — provide a viable conceptual framework for effectively linking KM to systems thinking and organizational learning. In doing so, it offers a promising way for us to create and sustain organizational success.